**ATTACHMENT 11**

**Exelon Generation Company, LLC Calculation L-003445, "Core Thermal Power Uncertainty to Support MUR for LaSalle Unit 2"**

Exelon Nuclear

**ATTACHMENT 1**
**Design Analysis Major Revision**
**Cover Sheet**

**CC-AA-309-1001**
**Revision 5**

| | | | |
|---|---|---|---|
| **Design Analysis (Major Revision)** | | **Last Page No.** Attachment J, Page J1 | |
| **Analysis No.:** [1] | L-003445 | **Revision:** [2] | 001 |
| **Title:** [3] | Core Thermal Power Uncertainty to Support MUR for LaSalle Unit 2 | | |
| **EC/ECR No.:** [4] | 363450 | **Revision:** [5] | 000 |

| | | **Component(s):** [14] | |
|---|---|---|---|
| **Station(s):** [7] | LaSalle | See Attachment G | |
| **Unit No.:** [8] | 2 | | |
| **Discipline:** [9] | DEE, INDC | | |
| **Descrip. Code/Keyword:** [10] | I04 | | |
| **Safety/QA Class:** [11] | NS | | |
| **System Code:** [12] | FW, C34, B33, E31, C11, G33 | | |
| **Structure:** [13] | N/A | | |

**CONTROLLED DOCUMENT REFERENCES** [15]

| Document No.: | From/To | Document No.: | From/To |
|---|---|---|---|
| EC 363450 | TO | See Sect. 4.3 for a list of drawings | FROM |
| L-002513 | FROM | | |
| L-003444 | FROM | | |
| NED-I-EIC-0214 | FROM | | |

**Is this Design Analysis Safeguards Information?** [16] Yes ☐ No ☒ If yes, see SY-AA-101-106

**Does this Design Analysis contain Unverified Assumptions?** [17] Yes ☐ No ☒ If yes, ATI/AR#:

**This Design Analysis SUPERCEDES:** [18] N/A **in its entirety.**

**Description of Revision** (list affected pages for partials): [19] Initial issue (MUR input)

This calculation is prepared to support a License Amendment Request for an increase in licensed power. Therefore there is no effect on any operating margin.

**Preparer:** [20] Hassan Ali (Print Name) [signature] (Sign Name) 11-13-09 (Date)

**Method of Review:** [21] Detailed Review ☒ Alternate Calculations (attached) ☐ Testing ☐

**Reviewer:** [22] SHARAD V PARIKH (Print Name) [signature] (Sign Name) 11-13-09 (Date)

**Review Notes:** [23] Independent review ☒ Peer review ☐

Performed line by line review of the calc. All comments have been incorporated

(For External Analyses Only)
**External Approver:** [24] Richard H. Low (Print Name) [signature] (Sign Name) 11/13/2009 (Date)

**Exelon Reviewer:** [25] ELIZABETH ZACHARIAS (Print Name) [signature] (Sign Name) 11/16/09 (Date)

**Independent 3rd Part Review Reqd?** [26] Yes ☒ No ☐ MPR did ITPR for this Calculation SEAG # 09-000201

**Exelon Approver:** [27] Vikram Shah (Print Name) [signature] (Sign Name) 11/17/09 (Date)

## CALCULATION TABLE OF CONTENTS

| CALCULATION NO. L-003445 | Revision 001 | PAGE NO. 2 |
|---|---|---|
| **SECTION:** | **PAGE NO.** | **SUB-PAGE NO.** |



| SECTION: | PAGE NO. | SUB-PAGE NO. |
|---|---|---|
| DESIGN ANALYSIS COVER SHEET | 1 | |
| OWNERS ACCEPTANCE REVIEW CHECKLIST | | 1a |
| TABLE OF CONTENTS | 2 | |
| 1 PURPOSE | 4 | |
| 2 INPUTS | 4 | |
| 3 ASSUMPTIONS AND LIMITATIONS | 6 | |
| 4 REFERENCES | 7 | |
| 5 METHOD OF ANALYSIS | 9 | |
| 6 NUMERIC ANALYSIS | 15 | |
| 7 CONCLUSIONS | 19 | |
| 8 APPENDICES | 19 | |
| Appendix A –RWCU Flow Loop Error Calculation | | 1-8 |
| Appendix B – RWCU Temperature Loop Error Calculation | | 1-6 |
| Appendix C – CRD Flow Loop Error Calculation | | 1-16 |
| Appendix D – RR Pump Motor Power Loop Error Calculation | | 1-9 |

## CALCULATION TABLE OF CONTENTS (CONT.)

| CALCULATION NO. L-003445 | Revision 001 | PAGE NO. 3 |
|---|---|---|
| ATTACHMENTS | | |
| ATTACHMENT A, RTP Corp. Card, Vendor Data | | A1-A4 |
| ATTACHMENT B, Rosemount Transmitters (Selected Pages) | | B1-B10 |
| ATTACHMENT C, Rosemount Nuclear Instruments Letter | | C1-C2 |
| ATTACHMENT D, GE Control Rod Drive Spec. (Selected Pages) | | D1-D2 |
| ATTACHMENT E, Weed Instrument Thermocouple Vendor Data | | E1-E2 |
| ATTACHMENT F, Signal Resistor Unit Purchase Part | | F1-F2 |
| ATTACHMENT G, Component(s) List | | G1-G1 |
| ATTACHMENT H, Calibration Data Sheet for Loop 2C11-N004 | | H1-H1 |
| ATTACHMENT I, Thermodynamic Properties of Fluid Systems | | I1-I13 |
| ATTACHMENT J, Calibration Data Sheet for 2B33-R653A | | J1-J1 |

## 1 PURPOSE

1.1 The purpose of this calculation is to determine the uncertainty in the reactor core thermal power (heat balance) calculation performed by the POWERPLEX-III core monitoring software. This calculation will evaluate the contribution of the uncertainties of the different instrument channel loops, which provide signals used by the POWERPLEX-III software to calculate core thermal power (CTP), to the uncertainty of the CTP value at rated power as documented in Figure 1.2-1 of the UFSAR.

This calculation is being performed in support of the licensing amendment for Measurement Uncertainty Recovery (MUR) power uprate.

## 2 INPUTS

2.1 The equation that the POWERPLEX-III core monitoring software uses to calculate core thermal power is (Reference 4.1.2):

$$CTP = Q_{fw} + Q_{cr} + Q_{cu} + Q_{rad} - Q_p$$

2.2 The design basis numbers for operation of LaSalle Unit 2 at 100% rated power, 3489 MWth, are listed in Figure 1.2-1, "Reactor System – Rated Power Heat Balance", of the UFSAR (Reference 4.6.1).

2.3 The conversion factor for converting million BTUs/hr to MWt is (Reference 4.1.2):

$$C_1 = 3.413 \text{ MBTU/MWh}$$

2.4 The table below lists the parameters which provide input to the core thermal power calculation, their uncertainty values and the source of these values:

| Description | Units | Nominal Value | Uncertainty (2σ) | Uncertainty Basis |
|---|---|---|---|---|
| Reactor Dome Pressure | PSIA | 1020.0<br>(Ref. 4.6.1) | ±19.067 | L-002513 |
| Feedwater Flow Rate | Mlbm/hr | WFW<br>15.113<br>(Ref. 4.6.1) | ± 0.0484 | L-003444 (0.32%*nom) |
| CRD Flow Rate | Mlbm/hr | WCR<br>0.0320<br>(Ref. 4.6.1) | ± 0.001602 | Appendix C |
| RWCU Flow Rate (352 gpm @ 532.6 °F) | Mlbm/hr | WCU<br>0.1330<br>(Ref. 4.6.1) | ± 0.005341 | Appendix A |
| Feedwater Temperature | °F | 426.5<br>(Ref. 4.6.1) | ± 0.57 | L-003444 |
| Control Rod Drive Temperature | °F | 80<br>(Ref. 4.6.1) | ± 10 | Section 3.3 |
| RWCU Suction Temperature | °F | 532.6<br>(Ref. 4.6.1) | ± 3.138 | Appendix B |
| RWCU Discharge Temperature | °F | 436.0<br>(Ref. 4.6.1) | ± 3.138 | Appendix B |
| Radiated and Misc Thermal Losses | MBTU/hr | QRAD<br>13.99<br>(Ref. 4.2.3) | ± 10 % | Section 3.4 |
| Recirc Pump Motor Energy Input | MW | QP<br>12.4<br>(Ref. 4.6.1) | ± 0.709 | Appendix D |
| Recirc Pump Motor efficiency | % | ETA<br>94.0<br>(Ref. 4.2.3) | ± 1 % | Section 3.5 |
| Saturated Steam Enthalpy (@ 1020 psia) | BTU/lbm | HG<br>1191.6<br>(Ref. 4.6.1) | ± 0.05 | Ref. 4.6.6 |
| Feedwater Enthalpy (subcooled @ 1020 psia) | BTU/lbm | HFW<br>404. 7<br>(Ref. 4.6.1) | ± 0.005 | Ref. 4.6.6 |
| CRD Enthalpy (subcooled @ 1020 psia) @ 80 °F | BTU/lbm | HCR<br>48.0<br>(Ref. 4.6.1) | ± 0.005 | Ref. 4.6.6 |
| RWCU Suction Enthalpy (subcooled @ 1020 psia) | BTU/lbm | HCU1<br>527.3<br>(Ref. 4.6.1) | ± 0.005 | Ref. 4.6.6 |
| RWCU Discharge Enthalpy (subcooled @ 1020 psia) | BTU/lbm | HCU2<br>415.1<br>(Ref. 4.6.1) | ± 0.005 | Ref. 4.6.6 |

## 3 ASSUMPTIONS AND LIMITATIONS

3.1 Calculation of M&TE errors is based on the assumption that the test equipment listed in each of the Appendices is used. The use of less accurate test equipment will require evaluation of the effect on the results of this calculation.

3.2 It is assumed that the equipment utilized to calibrate the M&TE is more accurate than the M&TE equipment by a ratio of at least 4:1 such that calibration standard errors can be considered negligible with respect to the M&TE specifications. This is considered a reasonable assumption since M&TE equipment is typically certified to its required accuracy under laboratory conditions using instrument standards (Reference 4.1.1, Appendix A, Section 5.1.4).

3.3 A conservative assumption has been made that CRD temperature variations are bounded by ± 10 °F of the design basis value based on engineering judgment. This is based on a 20 °F variation equaling 20% of the allowable range per Reference 4.5.4, and a review of other MUR submittals.

3.4 A conservative assumption has been made that the radiated and miscellaneous thermal loss value listed in Reference 4.2.3 is bounded by a ± 10% variation based on examination of other MUR submittals.

3.5 A conservative assumption has been made, based on Reference 4.4.1.2, that the RR Pump motor efficiency when the Unit is operating at design basis conditions is bounded by a ± 1% variation.

3.6 It is assumed that RWCU blow down flow during steady-state operations is 0 gpm based on Reference 4.6.1.

3.7 It is assumed that a 2 degree variation in steam temperature is sufficiently small such that the variation of enthalpy with pressure is linear for the calculation of steam enthalpy uncertainty. This is based on engineering judgment from review of the steam tables.

3.8 It is assumed that a ± 5 °F variation in temperature is sufficiently small such that the variation of enthalpy with temperature is linear for the calculation of liquid enthalpy uncertainty. This is based on engineering judgment from review of the steam tables.

3.9 It is assumed that a ± 30 psi variation in pressure is sufficiently small such that the variation of enthalpy with pressure is linear for the calculation of liquid enthalpy uncertainty. This is based on engineering judgment from review of the steam tables.

3.10 It is conservatively assumed that the moisture carryover fraction is 0 (Reference 4.1.2).

3.11 It is assumed that all variables used for calculation of the various enthalpies can be considered as independent based on engineering judgment, since enthalpies are relatively insentive to pressure and all flow and temperature measurements are provided by different instruments.

3.12 It is assumed that CRD and RWCU pressures are equal to Reactor Steam Dome Pressure for the calculation of CRD and RWCU enthalpy uncertainties based on the use of this pressure for calculation of these enthalpies in reference 4.1.2.

3.13 Since the vendor does not state a drift error for the PPC input cards, Reference 4.1.1, Appendix A, Section 3.1 provides a default value of 0.5% of span per refueling cycle for electronic devices.

However, the vendor includes a 0.5% error which is over conservative for a 16 bit A/D converter. Therefore, the 0.5% accuracy is considered to include drift.

3.14 If specific M&TE cannot be identified for performing a calibration, a conservative assumption is made that the M&TE used is at least as accurate as the reference accuracy of the instruments being calibrated.

## 4 REFERENCES

### 4.1 METHODOLOGY

4.1.1 NES-EIC-20.04, "Analysis of Instrument Channel Setpoint Error and Instrument Loop Accuracy," Revision 5

4.1.2 EMF-2469, Revision 8, POWERPLEX-III CMSS Software Design Specification

4.1.3 NUREG/CR-3659, A Mathematical Model for Assessing the Uncertainties of Instrumentation Measurements for Power and Flow of PWR Reactors

### 4.2 PROCEDURES

4.2.1 LIS-RT-201, Unit 2 Reactor Water Cleanup High Differential Flow Isolation Calibration, Rev. 20

4.2.2 LIP-GM-927, Thermocouple Loop Check, Rev. 4

4.2.3 LTP-1600-10, Calculating Core Thermal Power, Rev. 27

4.2.4 MA-LA-773-472, Unit 2 RR System/Meter Calibrations By OAD, Rev. 6

### 4.3 LASALLE STATION DRAWINGS

4.3.1 1E-2-4224AB, Schematic Diagram, Leak Detection System “LD” (E31) Part 2, Rev. I

4.3.2 1E-2-4707AQ, Wiring Diagram Analog Input Cabinet 2C91-P618 AITs 1,2,3,4 Right Side, Rev. E

4.3.3 1E-2-4707AX sheet 3, Wiring Diagram Analog Input Cabinets 2C91-P607, P617, P618, P631, & P635, Rev. A

4.3.4 1E-2-4207AE, Schematic Diagram – Cont. Rod Drive Hyd. Sys. RD (C11B) PT. 5, Rev. F

4.3.5 M-2097 sheet 2, P&ID/C&I Details Reactor Water Clean Up System - RT, Rev. J

4.3.6 1E-2-4228AG, Schematic Diagram – Reactor Water Cleanup System “RT” (G33) Part 7, Rev. P

4.3.7 1E-2-4707AG, Wiring Diagram – Analog Input Cabinet 2C91-P617 AIT’S 1,2,3,4 Left Side, Rev. M

4.3.8 1E-2-4707AK, Wiring Diagram – Analog Input Cabinet 2C91-P617 AIT’S 5,6,7,8 Left Side, Rev. J

4.3.9 1E-2-4000PC, Relaying & Metering Diagram Reactor Recirculation Pumps 2A & 2B, Rev. M

### 4.4 GENERAL ELECTRIC (GE) DRAWINGS

4.4.1 Reactor Recirculation System Drawings:

4.4.1.1 234A9302TD sheet 21, IDS Recirculation System LaSalle 1,2, Rev. 4

4.4.1.2 421H151, Performance Specifications for Nuclear Reactor Recirculating Pump Motors – Induction Type, Rev. 4

4.4.2 234A9303 sheet 2, IDS CRD Hydraulic System, Rev. 8

4.4.3 158B7077A, Flow Nozzle, Rev. 4

**4.5 VENDOR PRODUCT INFORMATION**

4.5.1 RTP Corp. 8436/32 8-Channel Isolated Low-Level Analog Input Card, Vendor Data Sheet 08/2004 (Attachment A)

4.5.2 Rosemount® 1153 Series B Pressure Transmitter Product Manual 00809-0100-4302, Rev BA (Attachment B)

4.5.3 Rosemount® 1151 Pressure Transmitter Product Manual 00813-0100-4360, Rev HA March 2008 (Attachment B)

4.5.4 GE Control Rod Drive System Design Specification, #22A4260, revision 4 (Attachment D)

4.5.5 Weed Instrument Nuclear Qualified Thermocouple Assemblies Product Sheet 10/99 (Attachment E)

4.5.6 RTP Corp. 8436/30 Isolated Thermocouple Card, Vendor Data Sheet 09/1998 (Attachment A)

**4.6 OTHER REFERENCES**

4.6.1 LaSalle UFSAR, Rev. 17, Figure 1.2-1, Tables 3.11-15 and 3.11-24

4.6.2 PASSPORT data as of 8/10/2009

4.6.3 Edwards, Jerry L. Rosemount Nuclear Instruments letter in reference to "Grand Gulf Nuclear Station message on INPO plant reports, subject Rosemount Instrument Setpoint Methodology, dated March 9, 2000". Letter dated 04/04/2000. (Attachment C)

4.6.4 NED-I-EIC-0255, "Measurement and Test Equipment (M&TE) Accuracy Calculation For Use With Commonwealth Edison Company Boiling Water Reactors," Revision 0

4.6.5 ASME, "Fluid Meters Their Theory and Application" Sixth Edition, 1971.

4.6.6 Lemmon, E.W., McLinden, M.O., and Friend, D.G., "Thermodynamic Properties of Fluid Systems", Chemistry WebBook, NIST Standard Reference Database Number 69, Eds. P.J. Linstrom and W.G. Mallard, National Institute of Standards Technology, Gaithersburg MD, 20899, http://webbook.nist.gov, (retrieved October 21, 2009) (Attachment I)

4.6.7 195B9537 Sheet 6 & Sheet 9, Signal Resistor Unit Purchase Part, Rev. 16 (Attachment F)

4.6.8 Evaluation No. 2009-03676, "LaSalle PEPSE MUR PU and EPU Heat Balances", Revision 1.

4.6.9 Calibration Data Sheets for loop 2C11-N004 (Attachment H)

4.6.10 DELETED

4.6.11 NED-I-EIC-0214, "Reactor Water Cleanup High Differential Flow Isolation", Revision 000B

4.6.12 L-002513, Reactor Dome Narrow Range Pressure IndicationError at the Plant Computer

4.6.13 L-003444, Bounding Uncertainty Analysis for Thermal Power Determination at LaSalle Unit 2 using the LEFM√+ System

4.6.14 Calibration Data Sheet for 2B33-R653A (Attachment J)

## 5 METHOD OF ANALYSIS

5.1 The reactor heat balance for a BWR reactor is provided by the formula stated in Section 2.1 and is repeated here for continuity in the development of the computation of the various uncertainty terms.

**Equation 1,**

$$CTP = Q_{fw} + Q_{cr} + Q_{cu} + Q_{rad} - Q_p$$

where

- CTP = Core Thermal Power
- $Q_{fw}$ = net power transferred to feedwater (MWth)
- $Q_{cr}$ = net power transferred to Control Rod Drive (CRD) cooling water (MWth)
- $Q_{cu}$ = net power transferred to the Reactor Water Clean Up (RWCU) system (MWth)
- $Q_{rad}$ = net power radiated to the Drywell and other thermal losses (MWth)
- $Q_p$ = net power input to the reactor coolant by the Reactor Recirculation (RR) pumps (MWth)

The POWERPLEX-III core monitoring software calculates the energy terms for feedwater, CRD and RWCU by multiplying the fluid mass flow by the enthalpy increase of the fluid added by the reactor. The energy loss due to radiated heat to the Drywell and other losses is a constant currently estimated at 13.99 MBTU/hr (Reference 4.2.3). The energy contribution to the feedwater from the RR Pumps is calculated by multiplying the electrical power consumed by the pump motors, as measured by the pump motor watt transducers, by an efficiency factor of 0.94 (References 4.1.2 and 4.2.3).

Expressing the energy terms for $Q_{fw}$, $Q_{cr}$, and $Q_{cu}$ from Equation 1 in terms of mass flow, W, and enthalpy, H, and adding the conversion factor for MBTU/MWth as documented in Reference 4.1.2, results in the following equation:

**Equation 2,**

$$CTP = \frac{WFW*((HG-FM*HFG)-HFW)+WCR*((HG-FM*HFG)-HCR)+[WCU*HCU1-(WCU-WCU_{bd})*HCU2)]+QRAD}{C1} - QP$$

Where:

*WFW is FeedwaterMass Flow Rate (lbm/hr)*

*HG is Saturated Steam Enthalpy (BTU/lbm)*

*FM is Moisture Carryover Fraction (%)*

*HFG is Latent Heat of Vaporization (BTU/lbm)*

*HFW is Feedwater Enthalpy (BTU/lbm)*

*HCR is Control Rod Drive Water Enthalpy (BTU/lbm)*

*WCR is CRD Mass Flow Rate (lbm/hr)*

*WCU is RWCU Mass Flow Rate (lbm/hr)*

*$WCU_{bd}$ is RWCU Blowdown Mass Flow Rate (lbm/hr)*

*HCU1 is RWCU Suction Enthalpy (BTU/lbm)*

*HCU2 is RWCU Discharge Enthalpy (BTU/lbm)*

*QRAD is Radiated and Other Heat Losses (BTU/hr)*

*QP is RR Pump Power (MW)*

*C1 is BTU/hr to MWth Conversion*

Per Section 4.6.1, RWCU blowdown flow is assumed to be zero during steady state operation. Per Section 3.10, a moisture carryover fraction of 0% is assumed to conservatively overestimate reactor power.

Setting $WCU_{bd}$ and FM equal to 0 reduces Equation 2 to the following equation:

**Equation 3,**

$$CTP = \frac{WFW*(HG-HFW)+WCR*(HG-HCR)+WCU*(HCU1-HCU2)+QRAD}{C1} - QP$$

In equation 3 above, the energy input to the feedwater by the RR Pumps is not measured directly but is calculated by multiplying the measured electrical power consumption of the RR pump motors by their efficiency. As a result QP can be expressed as $QP_{elec}$ * ETA where ETA is the RR pump motor efficiency.

All mass flows and fluid temperatures are measured via independent instruments. As such, all input variables are modeled as independent. Only the calculated enthalpy pressure effects are dependent since the steam dome pressure measured from the same instrument is applied in each calculation. However, considering the very small dependence of enthalpy on pressure and small uncertainty in steam dome pressure, this dependency is not expected to significantly affect the results (Section 3.11).

The mathematics of determining the uncertainty in CTP is developed in Reference 4.1.3. Equation 3 has been further evaluated using equation 16 of Reference 4.1.3 to determine uncertainty of core thermal power variables. Per Section 3.11 all variables are considered to be independent so all of the cross product terms from the squaring operation are zero.

Performing the partial derivative and squaring operations on Equation 3 above with the RR pump power contribution expressed as QP * ETA yields the following result.

**Equation 4,**

$$U_{CTP}^2 = [((\frac{\partial CTP}{\partial WFW})^2 * \sigma_{WFW}^2) + ((\frac{\partial CTP}{\partial HG_{FW}})^2 * \sigma_{HG}^2) + ((\frac{\partial CTP}{\partial HG_{CR}})^2 * \sigma_{HG}^2) + ((\frac{\partial CTP}{\partial WCR})^2 * \sigma_{WCR}^2) +$$
$$((\frac{\partial CTP}{\partial WCU})^2 * \sigma_{WCU}^2) + ((\frac{\partial CTP}{\partial HCU1})^2 * \sigma_{HCU1}^2) + ((-\frac{\partial CTP}{\partial HCU2})^2 * \sigma_{HCU2}^2) + ((-\frac{\partial CTP}{\partial HFW})^2 * \sigma_{HFW}^2)$$
$$+ ((-\frac{\partial CTP}{\partial HCR})^2 * \sigma_{HCR}^2) + ((\frac{\partial CTP}{\partial QRAD})^2 * \sigma_{QRAD}^2) + ((\frac{\partial CTP}{\partial ETA})^2 * \sigma_{ETA}^2) + ((\frac{\partial CTP}{\partial QP})^2 * \sigma_{QP}^2)]$$

where the $\sigma^2$ terms are the variances (square of the standard deviation) of the different variables.

5.2 The partial derivative terms in Equation 4 can then be determined by taking the partial derivative of Equation 3 with respect to each of the variables with the following result:

$$\frac{\partial CTP}{\partial WFW} = HG - HFW$$

$$\frac{\partial CTP}{\partial HG_{FW}} = WFW$$

$$\frac{\partial CTP}{\partial HG_{CR}} = WCR$$

$$\frac{\partial CTP}{\partial WCR} = HG - HCR$$

$$\frac{\partial CTP}{\partial WCU} = HCU1 - HCU2$$

$$\frac{\partial CTP}{\partial HCU_{FW}} = WCU$$

$$\frac{\partial CTP}{\partial HCU_{CR}} = -\ WCU$$

$$\frac{\partial CTP}{\partial HFW} = -\ WFW$$

$$\frac{\partial CTP}{\partial HCR} = -WCR \quad \frac{\partial CTP}{\partial QRAD} = 1$$

$$\frac{\partial CTP}{\partial ETA} = -\ QP_{elec}$$

$$\frac{\partial CTP}{\partial QP} = -\mathrm{ETA}$$

5.3 To complete the CTP uncertainty calculation, the enthalpy uncertainties must be computed. Since enthalpy varies with pressure and temperature, the partial differential of each enthalpy term will be taken with respect to temperature, pressure and the uncertainty, $I_O$, inherent in the steam tables. The results will be squared to provide a statistical average and the square root of the result taken to provide the standard deviation of the enthalpy. Per section 3.11 the enthalpy variables are considered independent so all of the cross product terms can be set to zero. The result of these mathematical operations is Equation 5 below and is used as the basis for determining the enthalpy uncertainties:

**Equation 5,**

$$\sigma_h = \sqrt{\left(\frac{\partial h}{\partial T}\right)^2 (\sigma_t)^2 + \left(\frac{\partial h}{\partial P}\right)^2 (\sigma_p)^2 + \left(\frac{\partial h}{\partial I_O}\right)^2 (\sigma_{I_o})^2}$$

Per sections 3.3, 3.4, 3.5, 3.7, 3.8 and 3.9, the variation of enthalpy with T, P and $I_O$ is considered to be linear. Therefore Equation 5 can be expressed as:

**Equation 6,**

$$\sigma_h = \sqrt{(\frac{\Delta H}{\Delta T})^2 (\sigma_T)^2 + (\frac{\Delta H}{\Delta P})^2 (\sigma_P)^2 + (\frac{\Delta H}{\Delta I_O})^2 (\sigma_{I_o})^2}$$

The calculation of uncertainty for saturated steam enthalpy, $\sigma_{HG}$, uses a modified form of Equation 5 above since temperature input is not required to determine saturation enthalpy for vapor. Thus $\frac{\Delta H}{\Delta T}$ is set to 0 and the uncertainty associated with the saturated steam enthalpy is expressed as:

$$\sigma_{HG} = \sqrt{(\frac{\Delta HG}{\Delta P})^2 (\sigma_P)^2 + (\frac{\Delta HG}{\Delta I_O})^2 (\sigma_{I_o})^2}$$

Where: HG is the enthalpy of saturated steam (BTU/lbm).

P is the steam dome pressure (psia).

$I_O$ is the accuracy of the steam table information.

The uncertainty associated with the control rod system water enthalpy is expressed as:

$$\sigma_{HCR} = \sqrt{(\frac{\Delta HCR}{\Delta TCR})^2 (\sigma_{TCR})^2 + (\frac{\Delta HCR}{\Delta P})^2 (\sigma_P)^2 + (\frac{\Delta HCR}{\Delta I_O})^2 (\sigma_{I_o})^2}$$

Where: HCR is the enthalpy of CRD system water (BTU/lbm).

P is the steam dome pressure (psia).

$I_O$ is the accuracy of the steam table information.

TCR is the CRD water temperature (° F).

The uncertainty associated with the feedwater enthalpy is expressed as:

$$\sigma_{HFW} = \sqrt{(\frac{\Delta HFW}{\Delta TFW})^2 (\sigma_{TFW})^2 + (\frac{\Delta HFW}{\Delta P})^2 (\sigma_P)^2 + (\frac{\Delta HFW}{\Delta I_O})^2 (\sigma_{I_o})^2}$$

Where: HFW is the feedwater enthalpy (BTU/lbm).

TFW is the feedwater temperature (° F).

P is the steam dome pressure (psia).

$I_O$ is the accuracy of the steam table information.

The uncertainty associated with the RWCU suction enthalpy is expressed as:

$$\sigma_{HCU1} = \sqrt{(\frac{\Delta HCU1}{\Delta TCU1})^2 (\sigma_{TCU1})^2 + (\frac{\Delta HCU1}{\Delta P})^2 (\sigma_P)^2 + (\frac{\Delta HCU1}{\Delta I_O})^2 (\sigma_{I_o})^2}$$

Where: HCU1 is the RWCU suction enthalpy (BTU/lbm).

TCU1 is the RWCU suction temperature (° F).

P is the steam dome pressure (psia).

$I_O$ is the accuracy of the steam table information.

The uncertainty associated with the RWCU discharge enthalpy is expressed as:

$$\sigma_{HCU2} = \sqrt{(\frac{\Delta HCU2}{\Delta TCU2})^2(\sigma_{TCU2})^2 + (\frac{\Delta HCU2}{\Delta P})^2(\sigma_P)^2 + (\frac{\Delta HCU2}{\Delta I_O})^2(\sigma_{I_O})^2}$$

Where: HCU2 is the RWCU discharge enthalpy (BTU/lbm).

TCU2 is the RWCU discharge temperature (° F).

P is the steam dome pressure (psia).

$I_O$ is the accuracy of the steam table information.

5.4 The rated Reactor Dome Pressure value is used to calculate the different enthalpies (Section 3.12).

5.5 For calculation of the loop uncertainties in the Appendices, temperature, humidity and pressure errors, when available from the manufacturer, are evaluated with respect to the conditions specified in the station EQ Zones. If not provided, an evaluation is made to ensure that the environmental conditions are bounded by the manufacturer's specified operational limits. If the environmental conditions are bounded, these error effects are considered to be included in the manufacturer's reference accuracy (Reference 4.1.1, Appendix I).

5.6 For calculation of the loop uncertainties in the Appendices, published instrument vendor specifications are considered to be based on sufficiently large samples so that the probability and confidence level meets the 2σ criteria, unless stated otherwise by the vendor (Reference 4.1.1, Appendix A, Section 8.0).

5.7 For calculation of the loop uncertainties in the Appendices, seismic effects are considered negligible or capable of being calibrated out (Reference 4.1.1, Appendix I, Section 2.5). Since there is no difference between normal operating and calibration conditions with respect to vibration effects, these are considered to be calibrated out (Ref. 4.1.1, Appendix I, Section 2.5)

5.8 For calculation of the loop uncertainties in the Appendices, the calibration standard error is considered negligible (Section 3.2).(

5.9 For calculation of the loop uncertainties in the Appendices, the insulation resistance error is considered negligible because operation of the instrumentation in an abnormal or harsh environment is not considered by this calculation. (Reference 4.1.1, Appendix A, Section 7.0).

5.10 It is expected that regulated instrument power supplies are designed to function within supply voltage limits. Therefore, the power supply error is considered negligible with respect to other error terms unless the vendor specifically specifies a power supply effect (Reference 4.1.1, Appendix I, Section 2.3).

5.11 The methodology used to calculate the loop uncertainties for RWCU flow and temperature, CRD flow and RR Pump motor power in the Appendices is based on NES-EIC-20.04 "Analysis of Instrument Channel Setpoint Error and Instrument Loop Accuracy" (Reference 4.1.1).

These are non-safety-related indication loops, but the indication is used to calculate Core Thermal Power, which is a licensing limit. Per Reference 4.1.1, the Level 2 methodology is appropriate for a licensing limit. The Level 2 methodology specifies combining the random errors via square-root-sum-of-the squares (SRSS). However, because this parameters are used as inputs to significant plant evaluations such as determination of Core Thermal Power, this analysis will use the Level 1 methodology of Reference 4.1.1 and express the results as $2\sigma$ numbers. The random errors are combined via Square Root Sum of the Squares (SRSS) and taken to a $2\sigma$ value, and then the non-random errors are added to the result. This is expressed as:

$$TE = 2\sigma + \Sigma e$$

5.12 The enthalpy uncertainty is determined by equating it to one half of the least significant digit with the number expressed to five significant digits. This is equal to ±0.05 BTU/lbm for steam and ± 0.005 BTU/lbm for liquid.

For steam, HG = 1191.6. Therefore, one half of 0.1 equals 0.05.

For feedwater, HFW = 404. 70. Therefore, one half of 0.01 equals 0.005.

## 6 NUMERIC ANALYSIS

6.1 Evaluation of the Enthalpy Uncertainties using Equation 6 (See Section 2.4 for referenced values). These values will be calculated at a 1 σ level:

The rated dome pressure for the heat balance calculation is 1020.0 psia. At this pressure the saturation temperature is 547.06 °F (Ref. 4.6.6). Per section 3.7, a ± 1 °F variation will be used to determine the variation in steam enthalpy with pressure. The temperatures that bound this value (546.06 °F and 548.06 °F) will be used to determine the corresponding pressures at saturation, and to establish the change in saturation steam enthalpy, HG, relative to the change in temperature.

Steam Enthalpy (BTU/lbm)

| T \ P | 1028.4 | 1020.0 | 1011.7 |
|---|---|---|---|
| 548.06 °F | 1192.3 | - | - |
| 547.06 °F | - | 1192.6 | - |
| 546.06 °F | - | - | 1193.0 |

$$\sigma_{HG} = \sqrt{\left(\frac{1193\frac{BTU}{lbm} - 1192.3\frac{BTU}{lbm}}{1011.7\,psia - 1028.4\,psia}\right)^2 * \left(\frac{19.067\,psi}{2}\right)^2 + \left(\frac{0.05\frac{BTU}{lbm}}{2}\right)^2} = 0.400\frac{BTU}{lbm}$$

The conditions used in the heat balance to describe the RWCU suction enthalpy, $HCU_1$, are a nominal pressure of 1020 psia and a rated temperature of 532.6 °F. Per Sections 3.8 and 3.9, a ± 5 °F variation and a ± 30 psi pressure variation will be used to determine the variation of liquid enthalpy with temperature and pressure. Reference 4.6.6 will be used to develop the entries in the following table to calculate the uncertainty in the enthalpy for the RWCU suction.

RWCU Suction Enthalpy (BTU/lbm)

| T \ P | 990 | 1020 | 1050 |
|---|---|---|---|
| 537.6 °F | 534.04 | 533.99 | 533.94 |
| 532.6 °F | 527.75 | 527.70 | 527.66 |
| 527.6 °F | 521.52 | 521.48 | 521.44 |

$$\sigma_{HCU} = \sqrt{\left(\frac{533.99\frac{BTU}{lbm} - 521.48\frac{BTU}{lbm}}{537.6^\circ F - 527.6^\circ F}\right)^2 * \left(\frac{3.138\,F}{2}\right)^2 + \left(\frac{527.75\frac{BTU}{lbm} - 527.66\frac{BTU}{lbm}}{1050\,psia - 990\,psia}\right)^2 * \left(\frac{19.067\,psi}{2}\right)^2 + \left(\frac{0.005\frac{BTU}{lbm}}{2}\right)^2} = 1.963\frac{BTU}{lbm}$$

The conditions used in the heat balance to describe the RWCU discharge enthalpy, $HCU_2$, are a nominal pressure of 1020 psia and a rated temperature of 436.0 °F. Per Sections 3.8 and 3.9, a ± 5 °F variation and a ± 30 psi pressure variation will be used to determine the variation of liquid enthalpy with temperature and pressure. Reference 4.6.6 will be used to develop the entries in the following table to calculate the uncertainty in the enthalpy for the RWCU discharge.

RWCU Discharge Enthalpy (BTU/lbm)

| T \ P | 990 | 1020 | 1050 |
|---|---|---|---|
| 431.0 °F | 409.77 | 409.80 | 409.82 |
| 436.0 °F | 415.27 | 415.29 | 415.32 |
| 441.0 °F | 420.79 | 420.81 | 420.84 |

$$\sigma_{HCU2} = \sqrt{\left(\frac{420.81\frac{BTU}{lbm} - 409.80\frac{BTU}{lbm}}{441^\circ F - 431^\circ F}\right)^2 * \left(\frac{3.138^\circ F}{2}\right)^2 + \left(\frac{415.32\frac{BTU}{lbm} - 415.27\frac{BTU}{lbm}}{1050psia - 990psia}\right)^2 * \left(\frac{19.067psi}{2}\right)^2 + \left(\frac{0.005\frac{BTU}{lbm}}{2}\right)^2} = 1.727\frac{BTU}{lbm}$$

The conditions used in the heat balance to describe the feedwater enthalpy, HFW, are a nominal pressure of 1020 psia and a rated temperature of 426.5 °F. Per Sections 3.8 and 3.9, a ± 5 °F variation and a ± 30 psi pressure variation will be used to determine the variation of liquid enthalpy with temperature and pressure. Reference 4.6.6 will be used to develop the entries in the following table to calculate the uncertainty in the enthalpy for Feedwater, HFW.

Feedwater Enthalpy (BTU/lbm)

| T \ P | 990 | 1020 | 1050 |
|---|---|---|---|
| 431.5 °F | 410.32 | 410.35 | 410.37 |
| 426.5 °F | 404.84 | 404.87 | 404.90 |
| 421.5 °F | 399.39 | 399.42 | 399.44 |

$$\sigma_{HFW} = \sqrt{\left(\frac{410.35\frac{BTU}{lbm} - 399.42\frac{BTU}{lbm}}{431.5^\circ F - 421.5^\circ F}\right)^2 * \left(\frac{0.57^\circ F}{2}\right)^2 + \left(\frac{404.90\frac{BTU}{lbm} - 404.84\frac{BTU}{lbm}}{1050psia - 990psia}\right)^2 * \left(\frac{19.067psi}{2}\right)^2 + \left(\frac{0.005\frac{BTU}{lbm}}{2}\right)^2} = 0.312\frac{BTU}{lbm}$$

The conditions used in the heat balance to describe the CRD system water enthalpy, HCR, are a nominal pressure of 1020 psia and a temperature of 80 °F. Per Sections 3.8 and 3.9, a ± 5 °F variation and a ± 30 psi pressure variation will be used to determine the variation of liquid enthalpy with temperature and pressure. Reference 4.6.6 will be used to develop the entries in the following table to calculate the uncertainty in the enthalpy for the CRD water.

CRD System Water Enthalpy (BTU/lbm)

| T \ P | 990 | 1020 | 1050 |
|---|---|---|---|
| 85 °F | 55.768 | 55.848 | 55.929 |
| 80 °F | 50.794 | 50.875 | 50.957 |
| 75 °F | 45.820 | 45.902 | 45.984 |

$$\sigma_{HCR} = \sqrt{\left(\frac{55.848\frac{BTU}{lbm} - 45.902\frac{BTU}{lbm}}{85^\circ F - 75^\circ F}\right)^2 * \left(\frac{10^\circ F}{2}\right)^2 + \left(\frac{50.957\frac{BTU}{lbm} - 50.794\frac{BTU}{lbm}}{1050psia - 990psia}\right)^2 * \left(\frac{19.067psi}{2}\right)^2 + \left(\frac{0.005\frac{BTU}{lbm}}{2}\right)^2} = 4.973\frac{BTU}{lbm}$$

6.2 Calculation of the variation in CTP with the different variables from Equation 4 and Section 5.2:

$\frac{\partial CTP}{\partial WFW}$ = HG - HFW = 1191.6 BTU/lbm – 404.7 BTU/lbm = 786.9 BTU/lbm

$\frac{\partial CTP}{\partial HG_{FW}}$ = WFW = 15.113 Mlbm/hr

$\frac{\partial CTP}{\partial HG_{CR}}$ = WCR = 0.0320 Mlbm/hr

$\frac{\partial CTP}{\partial WCR}$ = HG - HCR = 1191.6 BTU/lbm – 48.0 BTU/lbm = 1143.6 BTU/lbm

$\frac{\partial CTP}{\partial WCU}$ = HCU1-HCU2 = 527.3 BTU/lbm – 415.1 BTU/lbm = 112.2 BTU/lbm

$\frac{\partial CTP}{\partial HCU1}$ = WCU = 0.1330 Mlbm/hr

$\frac{\partial CTP}{\partial HCU2}$ = -WCU = -0.1330 Mlbm/hr

$\frac{\partial CTP}{\partial HFW}$ = -WFW = -15.113 Mlbm/hr

$\frac{\partial CTP}{\partial HCR}$ = -WCR = -0.0320 Mlbm/hr

$$\frac{\partial CTP}{\partial ETA} = (-QP * 3.413(\tfrac{MBTU}{HR} / MWTH)) = (-12.4MW * 3.413(\tfrac{MBTU}{HR} / MWTH)) = -42.321\tfrac{MBTU}{HR}$$

$$\frac{\partial CTP}{\partial QP} = \text{-ETA} = \text{-0.94}$$

$$\frac{\partial CTP}{\partial QRAD} = QRAD = 13.99 \text{ MBTU/hr}$$

6.3 Calculation of the individual Uncertainty Values from Equation 4 using the values calculated in Section 6.2 and the uncertainty values from the table in Section 2.4:

$$(\frac{\partial CTP}{\partial WFW})^2 \sigma_{WFW}^2 = (786.9\tfrac{BTU}{lbm})^2 * (0.0484\tfrac{Mlb}{hr})^2 = 1450.540(\tfrac{MBTU}{hr})^2$$

$$(\frac{\partial CTP}{\partial HG_{FW}})^2 \sigma_{HG}^2 = (15.113\tfrac{Mlb}{hr})^2 * (2 * 0.400\tfrac{BTU}{lbm})^2 = 146.462(\tfrac{MBTU}{hr})^2$$

$$(\frac{\partial CTP}{\partial HG_{CR}})^2 \sigma_{HG}^2 = (0.0320\tfrac{Mlb}{hr})^2 * (2 * 0.400\tfrac{BTU}{lbm})^2 = 0.001(\tfrac{MBTU}{hr})^2$$

$$(\frac{\partial CTP}{\partial WCR})^2 \sigma_{WCR}^2 = (1143.6\tfrac{BTU}{lbm})^2 * (0.001602\tfrac{Mlb}{hr})^2 = 3.356(\tfrac{MBTU}{hr})^2$$

$$(\frac{\partial CTP}{\partial WCU})^2 \sigma_{WCU}^2 = (112.2\tfrac{BTU}{lbm})^2 * (0.005341\tfrac{Mlb}{hr})^2 = 0.359(\tfrac{MBTU}{hr})^2$$

$$(\frac{\partial CTP}{\partial HCU1})^2 \sigma_{HCU1}^2 = (0.1330\tfrac{Mlb}{hr})^2 * (2 * 1.963\tfrac{BTU}{lbm})^2 = 0.273(\tfrac{MBTU}{hr})^2$$

$$(\frac{\partial CTP}{\partial HCU2})^2 \sigma_{HCU2}^2 = (-0.1330\tfrac{Mlb}{hr})^2 * (2 * 1.727\tfrac{BTU}{lbm})^2 = 0.211(\tfrac{MBTU}{hr})^2$$

$$(\frac{\partial CTP}{\partial HFW})^2 \sigma_{HFW}^2 = (-15.113\tfrac{Mlb}{hr})^2 * (2 * 0.312\tfrac{BTU}{lbm})^2 = 88.741(\tfrac{MBTU}{hr})^2$$

$$(\frac{\partial CTP}{\partial HCR})^2 \sigma_{HCR}^2 = (-0.0320\tfrac{Mlb}{hr})^2 * (2 * 4.973\tfrac{BTU}{lbm})^2 = 0.101(\tfrac{MBTU}{hr})^2$$

$$(\frac{\partial CTP}{\partial ETA})^2 \sigma_{ETA}^2 = (\text{-}42.321\tfrac{MBTU}{HR})^2 * (0.01)^2 = 0.179(\tfrac{MBTU}{hr})^2$$

$$(\frac{\partial CTP}{\partial QP})^2 \sigma_{QP}^2 = (-0.94)^2 * (0.709 MWTH * 3.413(\tfrac{MBTU}{HR} / MWTH))^2 = 5.174(\tfrac{MBTU}{hr})^2$$

$$(\frac{\partial CTP}{\partial QRAD})^2 \sigma_{QRAD}^2 = (13.99\tfrac{MBTU}{hr})^2 * (0.10)^2 = 1.957(\tfrac{MBTU}{hr})^2$$

6.4 Total CTP Uncertainty is calculated using Equation 4 as follows:

$$U_{CTP}^2 =$$

$$1450.540(\tfrac{MBTU}{hr})^2 + 146.462(\tfrac{MBTU}{hr})^2 + 0.001(\tfrac{MBTU}{hr})^2 + 3.356(\tfrac{MBTU}{hr})^2 + 0.359(\tfrac{MBTU}{hr})^2 + 0.273(\tfrac{MBTU}{hr})^2$$
$$+ 0.211(\tfrac{MBTU}{hr})^2 + 88.741(\tfrac{MBTU}{hr})^2 + 0.101(\tfrac{MBTU}{hr})^2 + 0.179(\tfrac{MBTU}{hr})^2 + 5.174(\tfrac{MBTU}{hr})^2$$
$$+ 1.957(\tfrac{MBTU}{hr})^2$$

$$U_{CTP}^2 = 1697.355(\tfrac{MBTU}{hr})^2$$

$$U_{CTP} = 41.199 \text{ MBTU/hr}$$

$$U_{CTP} = (41.197\frac{MBTU}{hr})/(3.413\frac{MBTU}{hr}/MWTH) = \pm 12.071 \text{ MWTH}$$

LaSalle Licensed Thermal Megawatts (CTP) = 3489 MWTH (Section 2.2)

Therefore the uncertainty in the CTP calculated by the POWERPLEX-III core monitoring software as a percentage of rated thermal power is:

$$U_{2\sigma} = \pm 12.071 \text{ MWTH} / 3489\text{MWTH} * 100\% = 0.346\ \%$$

## 7 CONCLUSIONS

The total uncertainty associated with reactor thermal power (heat balance) calculation performed by the POWERPLEX-III core monitoring software is 12.071 MWTH or 0.346 % of the current LaSalle licensed thermal power limit of 3489 megawatts. This is a 2σ number.

## 8 APPENDICIES

8.1 Appendix A – RWCU Flow Loop Error Calculation

8.2 Appendix B – RWCU Temperature Loop Error Calculation

8.3 Appendix C – CRD Flow Loop Error Calculation

8.4 Appendix D –RR Pump Motor Power Loop Error Calculation

**ATTACHMENTS**

Attachment A - RTP Corp. Card, Vendor Data

Attachment B - Rosemount Transmitters (Selected Pages)

Attachment C - Rosemount Nuclear Instruments Customer Letter

Attachment D - GE Control Rod Drive Spec. (Selected Pages)

Attachment E - Weed Instrument Thermocouple Vendor Data

Attachment F - Signal Resistor Unit Purchase Part

Attachment G - Component(s) List

Attachment H – Calibration Data Sheet for Loop 2C11-N004

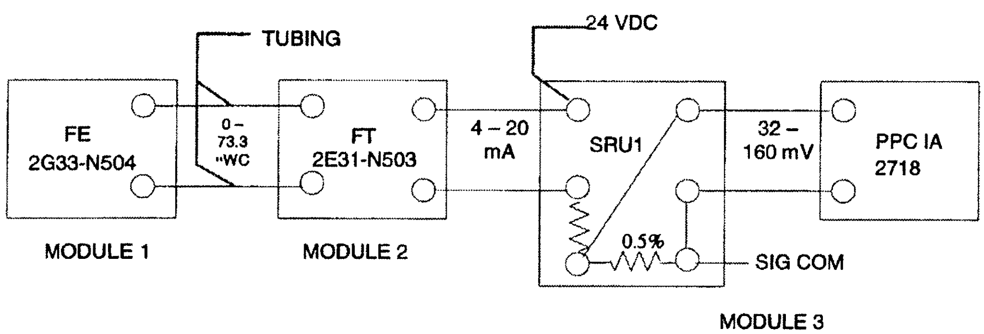
Attachment I – Thermodynamic Properties of Fluid Systems

Attachment J, Calibration Data Sheet for 2B33-R653A

The purpose of this Appendix is to calculate the uncertainty in RWCU mass flow rate at rated conditions of 3489 MWth for insertion into the table in Section 2.4 of the calculation.

1.0 Reactor Water Clean-up (RWCU) Flow Loop Configuration

1.1 RWCU flow is measured by a venturi tube flow meter located on the suction side of the RWCU Recirculation Pumps, which provides a dp signal to a Rosemount transmitter. The transmitter supplies a 4-20 milliamp signal to a signal resistor unit (SRU) which converts the signal to 32-160 millivolts for input to the PPC for display in the Control Room. The analyzed instrument loop consists of the following: flow element, flow transmitter, SRU, and a PPC input/output (I/O) module. The loop configuration is shown below (Ref. 4.3.1):




Loop components 2G33-N504 (Module 1) and 2E31-N503 (Module 2) are evaluated by Reference 4.6.11.

The applicable flow and dP values from Reference 4.6.11, Section 11.1.2.6.1.4, are as follows:

| | |
|---|---|
| Full Scale Inlet Flow | 400 gpm |
| dP @ Full Scale Inlet Flow | 73.3 "W.C. |
| Required (Nominal) Inlet Flow | 352 gpm |
| Required (Nominal) Inlet dP | 56.76 "W.C. |

The error values determined by Reference 4.6.11 are as follows:

Transmitter Total Random Error (Reference 4.6.11, Section 11.2.2.12.1)

$\sigma 2n_{C2} = \pm 0.426$ mA

]

Transmitter Total Non-Random Error (Reference 4.6.11, Section 11.2.4.4)

$\Sigma e2n_C = 0$ mA

The loop components evaluated in this document (and the applicable performance specifications and process parameter data) are as follows:

1.2 Signal Resistor Unit (SRU) (Ref. 4.6.7)

| | |
|---|---|
| Resistance: | 8 ohms |
| Tolerance: | ± 0.5% |

1.3 PPC I/O (low level analog input) cards for computer point IA1718 (Ref. 4.3.2 & 4.3.3):

RTP 8436-32 8 Channel Isolated Low Level Analog Input Card performance specifications (Ref. 4.5.1)

| | |
|---|---|
| Accuracy: | ± 0.50% of full scale (32°F to 131°F) |
| Full Scale Voltage: | ± 160 mV |

1.4 Local Service Environment (Ref.4.6.1):

| | **Plant Process Computer** |
|---|---|
| **EQ Zone** | C1A |
| **Location** | Control Room (Computer Room) |
| **Temperature** | 50°F to 104°F (Normal: 65 to 85°F) |
| **Pressure** | 0.125 to 3.0 "wc |
| **Humidity** | 2.6 to 90% RH (Normal expected: 20-50%) |

1.5 Calibration Instrument Data

Per references 4.2.1, the loop is calibrated using a pressure source to simulate pressure input to the transmitter (measured by a pressure gauge for $MTE1_{IN}$). The calibration error due to $MTE1_{IN}$ is accounted for in the uncertainty value calculated in Reference 4.6.11. The PPC I/O card is not adjusted as part of this calibration. The output at the computer point is verified to read within ± 4000 lbm/hr of the desired value (Reference 4.2.1). This is converted to a gpm value for setting tolerance at rated conditions of 532.6 °F (Reference 4.6.1) as follows:

$$ST = \pm (4000 \text{ lbm/hr}) / ((8.3445 \text{ lb/gal @ sp gr} = 1) * (0.7547 \text{ sp gr @ } 532.6\ ^\circ\text{F}) * 60 \text{ min/hr}))$$

$$ST = \pm 10.6 \text{ gpm}$$

2.0 Reactor Water Clean-up (RWCU) Flow Loop Uncertainty

2.1 PPC I/O Module Errors (Module 3) Random Error, Normal Conditions $\sigma 3$

2.1.1 Reference Accuracy **RA3**

Reference Accuracy is specified as ± 0.50% of full scale voltage (FSV) (paragraph 1.3) and considered to be a 2σ value (Section 5.6)

$RA3_{2\sigma}$ = ± 0.50% * FSV

$RA3_{2\sigma}$ = ± 0.50% * (160 mV/100%)

$RA3_{2\sigma}$ = ± 0.80 mV

Converting to a 1σ value

$RA3_{1\sigma}$ = ± 0.80 mV / 2

= ± 0.40 mV

Converting to a in of WC value

$RA3_{1\sigma}$ = ± [73.3 "W.C. / (160 mV – 32 mV)] * 0.40 mV

$RA3_{1\sigma}$ = ± 0.229 inWC

Converting to % dp span

$RA3_{1\sigma}$ = ± [0.229 inWC / 73.3 inWC]*100

**$RA3_{1\sigma}$ = ± 0.313 % dp span**

2.1.2 Calibration Error **CAL3**

The I/O module is not individually calibrated. Therefore

**CAL3 = ± 0**

2.1.3 Setting Tolerance **ST3**

Per paragraph 1.5, the RWCU flow is read with a tolerance of ± 10.6 gpm. Per reference 4.1.1 this is considered to be a 3σ value.

Converting to a 1σ value

ST3 = ± 10.6 gpm / 3

ST3 = ± 3.533 gpm

Expressed as percent of nominal flow,

$ST3_{nom}$ = ± 3.533 gpm / 352 gpm * 100

$ST3_{nom}$ = ± 1.004%

Converting error to % dP span using equation G10 from Reference 4.1.1:

% full span dp error = ± (2 * % nominal flow error) / $(F_{max} / F_{nom})^2$

where $F_{max}$ and $F_{nom}$ are in % of $F_{nom}$.

% $F_{max}$ = (400/352) * 100

= 113.64%

% dp span error = ± (2 * 1.004) / (113.64% / 100%)$^2$

$ST3_{nom}$ = **± 1.555 % dp span**

2.1.4 Drift Error **D3**

The vendor does not specify a drift error for the I/O module. Per Section 3.13, it is considered to be included in the Reference Accuracy.

**D3 = ± 0**

2.1.5 Input error due to Signal Resistor **σ3r**

A ± 0.5 % tolerance 8 Ω resistor is connected across the input to the I/O card to develop the voltage signal read by the card (Ref. 4.3.1 and 4.6.7). The ± 0.5 % tolerance is considered to be a 2σ value (Section 5.6). The transmitter is scaled to provide a 4 – 20 mA output for 0 – 73.3 "W.C. dP input. At nominal flow (352 gpm), the dP presented to the transmitter is 56.76 "W.C. (paragraph 1.1). The transmitter output at this dP input is:

Flow Signal Out = (56.76 " W.C./ 73.3 " W.C.) * 16 mA + 4 mA

= 16.390 mA

Therefore, the maximum error due to the resistor at nominal flow (352 gpm) with the I/O card scaled for 32 – 160 mV equal to 0 – 73.3 "W.C. (paragraph 1.1) is

$\sigma 3r_{2\sigma} = \pm [(0.005) * 8\Omega]$

$\sigma 3r_{2\sigma} = \pm 0.040\ \Omega$

Converting to voltage error at the input to the I/O card:

$\sigma 3r_{2\sigma} = \pm [0.040\ \Omega * 16.390\ mA]$

$= \pm 0.656\ mV$

Converting to "W.C.:

$\sigma 3r_{2\sigma} = \pm [(0.656\ mV / (160 - 32\ mV)) * 73.3\ "W.C.]$

$= \pm 0.376\ "W.C.$

Converting to a $1\sigma$ value;

$\sigma 3r_{1\sigma} = \pm 0.376\ "W.C./2$

$= \pm 0.188\ "W.C.$

Converting to % of dP span;

$\sigma 3r = \pm (0.188/73.3) * 100$

**$\sigma 3r = \pm 0.256$ % of dP span**

2.1.6 Random Input Error **σ3in**

From paragraph 1.1;

$\sigma 3in = \sigma 2n_{C2} = \pm 0.426\ mA$

From Reference 4.6.11, the transmitter output is 4 – 20 mA for 0 – 73.3 "W.C. dP

Therefore, converting to % of dP span;

$\sigma 3in = \pm (0.426/16) * 100$

**$\sigma 3in = \pm 2.663$ % dp span**

2.1.7 Total Random Error **σ3**

$\sigma 3 = \pm [(RA3)^2 + (CAL3)^2 + (ST3)^2 + (\sigma D3)^2 + (\sigma 3r) + (\sigma 3in^2)]^{1/2}$

$\sigma 3 = \pm [(0.313)^2 + (0)^2 + (1.555)^2 + (0)^2 + (0.256)^2 + (2.663)^2]^{1/2}$

**$\sigma 3 = \pm 3.110$ % dp span**

2.2 PPC I/O Module Errors (Module 3) Non-Random Error, **Σe3**

2.2.1 Humidity Error **e3H**

No humidity effect errors are provided in the manufacturer's specifications. However, the I/O module is located in EQ Zone C1A, where humidity is maintained between 20 and 50% RH (Section 2.2.6). Therefore, humidity errors are considered to be negligible (Section 5.5).

**e3H = 0**

2.2.2 Radiation Error **e3R**

No radiation errors are provided in the manufacturer's specifications. However, the instrument is located in the Control Room, EQ Zone C1A, a controlled environment (paragraph 1.4). Therefore, it is reasonable to consider any radiation effect as negligible and capable of being calibrated out in accordance with Appendix I of Reference 4.1.1. Therefore,

**e3R = 0**

2.2.3 Seismic Error **e3S**

No seismic effect errors are provided in the manufacturer's specifications. A seismic event defines a particular type of accident condition. Therefore, there is no seismic error for normal operating conditions (Section 5.7).

**e3S = 0**

2.2.4 Static Pressure Offset Error **e3SP**

The I/O module is an electrical device and therefore not affected by static pressure.

**e3SP = 0**

2.2.5 Ambient Pressure Error **e3P**

The I/O module is an electrical device and therefore not affected by ambient pressure.

**e3P = 0**

2.2.6 Process Error **e3Pr**

The I/O module/signal resistor combination receive an analog current input from the flow transmitter proportional to the dP pressure sensed. Any process errors associated with the conversion of volume flow to pressure, and pressure to a current signal, have been accounted for as errors associated with modules 1 and 2. Therefore,

**e3Pr =** **0**

2.2.7 Non-Random Input Error **e3in**

From paragraph 1.1;

**e3in =** $\boldsymbol{\Sigma e2n_C = 0}$

2.2.8 Total Non-Random Error $\boldsymbol{\Sigma e3}$

$\Sigma e3$ = e3H + e3R + e3S + e3SP + e3P + e3r + e3in

= 0 + 0 + 0 + 0 + 0 + 0 + 0

$\boldsymbol{\Sigma e3}$ = **± 0**

3.0 Reactor Water Clean-up (RWCU) Flow Loop Uncertainty Total Error

$TE_{dP}$ = $\sigma 3 + \Sigma e3$ (in % dP span) [1σ]

$\boldsymbol{TE_{dP}}$ = **± 3.110 + 0**

Converting dP span errors to % nominal flow, $TE_{\%flow}$ (using Equation G10 in Ref. 4.1.1):

$TE_{\%flow}$ = (% dp error / 2) * $(F_{max}/F_{nom})^2$ + (% dp error / 2) * $(F_{max}/F_{nom})^2$

$TE_{\%flow}$ = (3.110 / 2) * (113.64 % / 100 )$^2$ + (0 / 2) * (113.64 % / 100 )$^2$

$TE_{\%flow}$ = ± 2.008 % flow + 0 [1σ]

Converting to a 2σ value,

TE = ± (2*2.008 % flow) + 0% flow

**TE = ± 4.016 % flow** [2σ]

Expressed in gpm:

TE = ± [4.016 % flow * 352 gpm] / 100

**TE = ± 14.136 gpm**

4.0 The total error due in the RWCU flow indication at the PPC at rated flow conditions is ± 4.016 % of flow or ± 14.136 gpm. Converting this to a mass flow number at the specific gravity of 0.7547 at rated conditions (Reference 4.6.2):

Weight of 1 gallon of water at a specific gravity of 1 is 8.3445 lbs (Reference 4.6.6)

Therefore:

$TE_{lbm}$ = ± 14.136 gpm * 8.3445 lb/gal* 0.7547 * 60 min/hr

**$TE_{lbm}$ = ± 5341.488 lbm/hr**

This value is entered into the table in Section 2.4 for RWCU Flow Rate under Uncertainty.

The purpose of this Appendix is to calculate the uncertainty in the RWCU Suction and Discharge temperature loops for insertion into the table in Section 2.4 of the calculation.

1.0 RWCU Inlet & Outlet Temperature Loop Configuration

1.1 The analyzed instrument loops consist of the following: thermocouples and PPC input/output (I/O) modules. The loop configuration is shown below (Ref. 4.3.6):

**MODULE 1**
**Thermocouples:**
**2G33-N004, 2G33-N015**

↓

**MODULE 2**
**Computer Points – 2741, 2742**

1.2 Weed Instruments Model 1J40D1-305-EG-A-2-C-008 (Reference 4.5.5 & 4.6.2) performance specifications:

| | |
|---|---|
| Temperature Range: | 32°F - 600°F |
| Limit of error (Reference Accuracy): | ±3°F |
| Thermocouple Type: | E |

1.3 PPC I/O (low level analog input) cards for computer points 2741 and 2742. (Refs. 4.3.3 & 4.3.7):

RTP 8436-30 8 Channel Isolated Thermocouple Input Card performance specifications (Ref. 4.5.6)

| | |
|---|---|
| Accuracy: | ±0.9°F (±0.5°C) |
| Resolution: | ±0.18°F (±0.1°C) |

1.4 Local Service Environments (Ref. 4.6.1):

| | Thermocouple | Plant Process Computer |
|---|---|---|
| EQ Zone | H4 | C1A |
| Location | Reactor Bldg. | Control Room (Computer Room) |
| Temperature | 94°F to 118°F | 50°F to 104°F (Normal: 65 to 85°F) |
| Pressure | 0.25 "wc | 0.125 to 3.0 "wc |
| Humidity | 23 to 35% RH | 2.6 to 90% RH (Normal expected: 20-50%) |

1.5 Calibration

Per Reference 4.2.2, this loop is only checked for operability and is not calibrated. Therefore, the setting tolerance will be set to 0.

2.0 RWCU Temperature Loop Uncertainty

2.1 Thermocouple Errors (Module 1) Random Error, **σ1**

2.1.1 Reference Accuracy **RA1**

Reference Accuracy is ± 3°F (Paragraph 1.2). This is considered a 2σ number per Section 5.6.

$RA1_{2\sigma} = \pm 3°F$ [2σ]

Converting to a 1σ value

$RA1_{1\sigma} = \pm 3°F / 2$

$\mathbf{RA1_{1\sigma} = \pm 1.5°F}$

2.1.2 Calibration Error **CAL1,** Calibration Standard Error **STD1,** Setting Tolerance **ST1** (paragraph 1.5):

The thermocouple has no adjustment, therefore

**CAL1=STD1=ST1= 0**

2.1.3 Drift Error **D1**

The thermocouple is not an electronic device, therefore,

$\mathbf{D1_{1\sigma} = 0}$

2.1.4 Power Supply Effects **σ1PS**

The thermocouple does not require a power supply, therefore,

$\boldsymbol{\sigma 1PS = 0}$

2.1.5 Ambient Temperature Error $\boldsymbol{\sigma 1T}$

All thermocouple extension wire junctions are on adjacent terminals and are assumed to be at the same temperature. Therefore,

$\boldsymbol{\sigma 1T = 0}$

2.1.6 Random Input Error $\boldsymbol{\sigma 1in}$

Module 1 is the first instrument in the loop, so

$\boldsymbol{\sigma 1in = 0}$

2.1.7 Total Random Error $\boldsymbol{\sigma 1}$

$$\sigma 1 = \pm [(RA1)^2 + (CAL1)^2 + (ST1)^2 + (D1)^2 + (\sigma 1PS)^2 + (\sigma 1T)^2 + (\sigma 1in)^2]^{1/2}$$

$$\sigma 1 = \pm [(1.5)^2 + (0)^2 + (0)^2 + (0)^2 + (0)^2 + (0)^2 + (0)^2]^{1/2}$$

$$\boldsymbol{\sigma 1 = \pm 1.5°F}$$

2.2 Thermocouple Errors (Module 1) Non-Random Error, $\boldsymbol{\Sigma e1}$

The thermocouple is not an electronic device and its output is only affected by temperature at the thermocouple junction. Therefore,

$\boldsymbol{e1H = e1R = e1S = e1V = e1SP = e1P} = 0$

2.2.1 Temperature Error **e1T**

The temperature error is assumed to be random and included in the reference accuracy. Therefore,

$\boldsymbol{e1T = 0}$

2.2.2 Non-Random Input Error **e1in**

The thermocouple is the first module in the loop. Therefore,

$\boldsymbol{e1in = 0}$

2.2.3 Total Non-Random Error $\boldsymbol{\Sigma e1}$

$$\Sigma e1 = e1H + e1R + e1S + e1SP + e1V + e1P + e1T + e1in$$

$= \quad 0 + 0 + 0 + 0 + 0 + 0 + 0 + 0$

$\mathbf{\Sigma e1 \quad = \quad 0}$

2.3 PPC I/O Module Errors (Module 2) Random Error, $\boldsymbol{\sigma 2}$

2.3.1 Reference Accuracy **RA2**

Reference Accuracy is specified as ± 0.9°F (paragraph 1.3) and considered to be a 2σ value (Section 5.6)

$RA2_{2\sigma} = \pm 0.9°F$

Converting to 1σ,

$RA2_{1\sigma} = \pm 0.9°F / 2$

$\mathbf{RA2_{1\sigma} = \pm 0.45°F}$

2.3.2 Resolution error **A/D2**

$A/D2 = \pm 0.18\ °F$

Converting to 1σ,

$A/D = \pm 0.18\ °F/2$

$\mathbf{A/D = \pm 0.09\ °F}$

2.3.3 Calibration Error **CAL2**

The I/O module is not calibrated. The calibration error for the loop is included in the verification of the indication for module 1. Therefore,

$\mathbf{CAL2 = \pm 0}$

2.3.4 Setting Tolerance **ST2**

The PPC I/O card has no adjustment. Therefore, there is no setting tolerance.

$\mathbf{ST2 = \pm 0}$

2.3.5 Drift Error **D2**

The vendor does not specify a drift error for the I/O module. Per Section 3.13, it is considered to be included in the Reference Accuracy.

$\mathbf{D2 = \pm 0}$

2.3.6 Random Input Error **σ2in**

$\sigma 2in = \sigma 1 = \pm 1.50°F$

$\boldsymbol{\sigma 2in = \pm 1.50°F}$

2.3.7 Total Random Error **σ2**

$$\sigma 2 = \pm [(RA2)^2 + (A/D2)^2 + (CAL2)^2 + (ST2)^2 + (D2)^2 + (\sigma 2in)^2]^{1/2}$$

$$\sigma 2 = \pm [(0.45)^2 + (0.09)^2 + (0)^2 + (0)^2 + (0)^2 + (1.50)^2]^{1/2}$$

$$\boldsymbol{\sigma 2 = \pm 1.569°F}$$

2.4 PPC I/O Module Errors (Module 2) Non-Random Error, Normal Conditions **Σe2**

2.4.1 Humidity Error **e2H**

No humidity effect errors are provided in the manufacturer's specifications (Ref. 4.5.1). Also, the I/O module is located in EQ Zone C1A, where humidity under normal conditions may vary from 20 to 50% RH (Section 2.3.6). Therefore, humidity errors are considered negligible (Section 5.2).

**e2H = 0**

2.4.2 Radiation Error **e2R**

No radiation errors are provided in the manufacturer's specifications. Also, the instrument is located in the Control Room, EQ Zone C1A, a mild environment (Section 2.3.6). Therefore, it is reasonable to consider any radiation effect as negligible and capable of being calibrated out in accordance with Appendix I of Reference 4.1.1. Therefore,

**e2R = 0**

2.4.3 Seismic Error **e2S**

No seismic effect errors are provided in the manufacturer's specifications. A seismic event defines a particular type of accident condition. Therefore, there is no seismic error for normal operating conditions (Section 5.4).

**e2S = 0**

2.4.4 Static Pressure Offset Error **e2SP**

The I/O module is an electrical device installed in the control room and is not subject to process pressure effects.

**e2SP** = **0**

2.4.5 Ambient Pressure Error **e2P**

The I/O module is an electrical device and therefore not affected by ambient pressure.

**e2P** = **0**

2.4.6 Non-Random Input Error **e2in**

**e2in** = **Σe1** = **0**

2.4.7 Total Non-Random Error **Σe2**

$$\Sigma e2 = e2H + e2R + e2S + e2SP + e2P + e2in$$

$$= 0 + 0 + 0 + 0 + 0 + 0$$

$$\mathbf{\Sigma e2 = 0}$$

2.5 RWCU Temperature Loop Uncertainty Total Error

$$TE = \sigma 2 + \Sigma e2$$

$$= \pm 1.569°F + 0 \qquad [1\sigma]$$

Expressed at a 2σ level of confidence

$$TE = 2\sigma 2 + \Sigma e2$$

$$= \pm 2 * 1.569 + 0$$

$$\mathbf{TE = \pm 3.138°F}$$

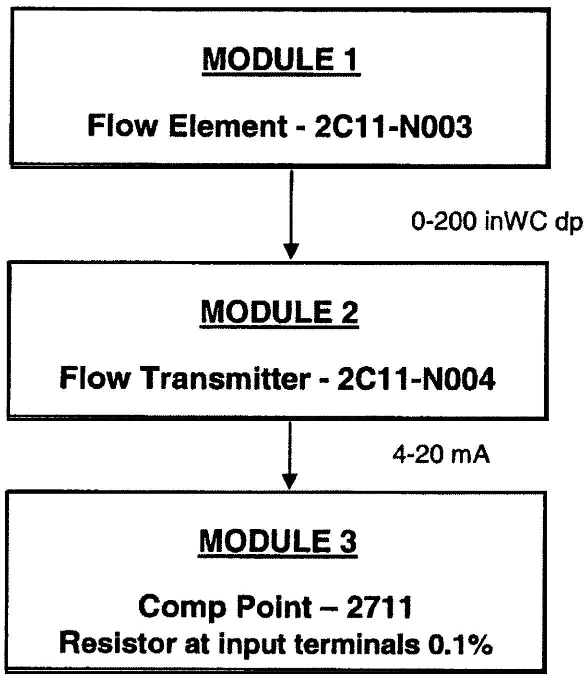
3.0 Conclusion

The total uncertainty in the RWCU Suction and Discharge temperature indications, expressed at a 2σ level of confidence, is ± 3.138°F. This value is inserted into the table in Section 2.4 for the RWCU Suction and Discharge temperatures under Uncertainty.

The purpose of this appendix is to calculate the uncertainty in the measurement of CRD flow for input to the table in Section 2.4 of the body of the calculation.

1.0 CRD Flow Loop Characteristics

1.1 Each analyzed instrument loop consists of a flow element supplying a differential pressure to a transmitter, and a PPC input/output (I/O) module with a precision resistor (8 Ω) across the input. The loop is shown as (Ref. 4.3.4):




The loop components evaluated in this document (and the applicable performance specification and process parameter data) are as follows:

1.2 Flow Element, EPN: 2C11-N003 (Ref. 4.4.2 and 4.6.2)

GE flow element part number 158B7077AP016 (Ref. 4.4.3)

| | |
|---|---|
| Maximum differential pressure | 200 inWC at 100 GPM |
| Accuracy | ± 1 % |

1.3 Flow Transmitter, EPN: 2C11-N004 (Ref. 4.6.2)

Rosemount Model 1151DP5E (Ref. 4.6.2) Flow Transmitter performance specifications (Ref. 4.5.3). These are considered 2σ numbers per section 5.6:

| | |
|---|---|
| Upper Range Limit (URL): | 750 inWC |
| Output Span: | 4 – 20 mA |
| Accuracy: | ±0.2% calibrated span [2σ] |
| Temperature Effect: [2σ] | ±(0.5% URL + 0.5% calibrated span)/100°F (-20 to 200 °F) |
| Drift: | ±0.2% URL for 6 months [2σ] |
| Temperature Operating Limits: | (-) 20°F to 200°F |
| Static Pressure Effect Zero Error | ±(0.25% URL/2000 psi) |
| Static Pressure Effect Span Error | ±(0.25% Input Reading/1000 psi) |
| Vibration Effect | 0.05% URL/g |
| Power Supply Effect | < 0.005% output span/volt |
| EMI/RFI Effect | < 0.1% span for 30 V/m between 20 and 1000 MHz |

Calibration information (Refs. 4.6.2):

| | |
|---|---|
| Calibration Range: | 0 – 200 inWC |
| Corresponding Process Range: | 0 – 100 GPM |
| Span | 200 inWC |

1.4 PPC I/O (low level analog input) cards for computer point IA2711. (Refs. 4.3.4 & 4.3.8):

RTP 8436-32 8 Channel Isolated Low Level Analog Input Card performance specifications (Ref. 4.5.1)

| | |
|---|---|
| Accuracy: | ±0.50% of full scale (32°F to 131°F) |
| Full Scale Voltage: | ±160 mV |

1.5 The signal resistor at the input terminals of the I/O card (Module 3) is a precision 8 ohm resistor with a tolerance of 0.10% (Ref. 4.3.4). This is considered to be a 2σ number because all resistors supplied meet this tolerance.

1.6 Process Parameters (Refs. 4.5.4, 4.6.1, 4.6.2 and 4.6.8):

| | |
|---|---|
| Process Fluid | Water |
| Process Press Max | 1410 PSIG |
| Steam Dome pressure - rated | 1005 PSIG |
| Process Temp Max | 95 °F |
| Process Temp at Rated Power | 80 °F |
| Process Temp Min | 40°F |
| Process Flow-Rated | 64 gpm |

1.7 Calibration Instrument Data

Per reference 4.6.9, the following M&TE are required.

Druck DPI-610 (15 psi), a 1 ohm precision resistor, and a Fluke 45 multimeter.

1.8 Local Service Environments (Reference: 4.6.1):

| | Pressure Transmitters | Plant Process Computer |
|---|---|---|
| **EQ Zone** | H4 | C1A |
| **Location** | Reactor Bldg. | Control Room (Computer Room) |
| **Temperature** | 94°F to 118°F | 50°F to 104°F (Normal: 65 to 85°F) |
| **Pressure** | 0.25 "wc | 0.125 to 3.0 "wc |
| **Humidity** | 23 to 35% RH | 2.6 to 90% RH (Normal expected: 20-50%) |

2.0 CRD Flow Loop Uncertainty

2.1 Flow Element (Module 1) Random Error, **$\sigma 1$**

The flow element is a mechanical device mounted in the process and cannot be calibrated. Therefore,

**CAL1 = ST1 = D1 = $\sigma$1PS = $\sigma$1T = 0**

2.1.1 Reference Accuracy **RA1**

Per reference 4.4.3, the accuracy of the flow element is ±1% of span. This is considered a $2\sigma$ number per section 5.3.

Therefore,

$RA1_{2\sigma}$ = ± 1%

Converting to $1\sigma$ value,

$RA1_{1\sigma}$ = ± 1% / 2

**$RA1_{1\sigma}$ = ± 0.5% dP span**

2.1.2 Temperature Effect on Element Expansion **TN1**

Per paragraph 1.6, the maximum temperature of the water passing through the flow element is 95°F and the normal temperature is 80 °F. Since the system temperature operation band is small, there is a minor change in the element expansion factor. The change is in order of 0.0007 or less for the temperature range of 70°F to 95 °F. Therefore the temperature effect on element expansion can be neglected.

**TN1 = 0**

2.1.3 Temperature Effect on Density **TD1**

Per paragraph 1.6, the maximum temperature of the water passing through the flow element is 95°F and the normal temperature is 80 °F. The change in water density for a temperature range of 70°F to 95 °F is approximately 0.2%. Therefore density effects are considered negligible.

**TD1 = 0**

2.1.4 Random Input Error **$\sigma$1in**

The flow element is the first device in the instrument loop. Therefore;

**$\sigma 1in$ = 0**

2.1.5 Total Random Error **$\sigma 1$**

$$\sigma 1 = \pm [(RA1)^2 + (CAL1)^2 + (ST1)^2 + (D1)^2 + (\sigma 1PS)^2 + (\sigma 1T)^2 + (\sigma 1in)^2 + (TN1)^2 + (TD1)^2]^{1/2}$$

$$\sigma 1 = \pm [(0.5\%)^2 + (0)^2 + (0)^2 + (0)^2 + (0)^2 + (0)^2 + (0)^2 + (0)^2 + (0)^2]^{1/2}$$

$$\mathbf{\sigma 1 = \pm 0.5\%\ dP\ Span}$$

2.2 Flow Element (Module 1) Non-Random Error, **$\Sigma e1$**

The flow element is a mechanical device mounted in the process and its output is not subject to environmental or vibration effects. Therefore;

**$e1H = e1R = e1P = e1T = 0$**

2.2.1 Seismic Error **e1S**

A seismic event is an abnormal operating condition and is not addressed by this calculation (Section 5.4). Therefore;

**$e1S = 0$**

2.2.2 Static Pressure Error **e1SP**

The flow element is constructed of stainless steel and is not affected by process pressure. Therefore,

**$e1SP = 0$**

2.2.3 Non-Random Input Error **e1in**

The flow element is the first device in the instrument loop. Therefore;

**$e1in = 0$**

2.2.4 Total Non-Random Error **$\Sigma e1$**

$$\Sigma e1 = e1H + e1R + e1P + e1T + e1S + e1SP + e1in$$

$$\Sigma e1 = 0 + 0 + 0 + 0 + 0 + 0 + 0$$

$$\mathbf{\Sigma e1 = \pm 0}$$

2.3 Flow Transmitter Errors (Module 2) Random Error, Normal Conditions $\sigma 2$

2.3.1 Reference Accuracy **RA2**

Reference Accuracy is ±0.2% of span (paragraph 1.3).

$RA2_{2\sigma}$ = ± 0.2% [$2\sigma$]

Converting to a $1\sigma$ value

$RA2_{1\sigma}$ = ± 0.2%/ 2

**$RA2_{1\sigma}$ = ± 0.1% dP span**

2.3.2 Calibration Error **CAL2**

The pressure loop is calibrated using a pressure source to simulate pressure input to the transmitter (measured by a digital pressure indicator for $MTE1_{IN}$), and reading the pressure on the computer point (Ref. 4.6.9). Therefore, only the digital pressure indicator contributes to the overall calibration error at the transmitter.

Measurement & Test Equipment Error **$MTE_{in}2$**

<u>Pressure Indicator</u>

Per paragraph 1.7, the pressure indicator used for calibration is a DRUCK DPI-601 gage with a range of 415 inWC. The measurement uncertainty, $MTE_{in}2$, for this indicator is specified in Reference 4.6.4 for an ambient temperature of 104 °F as:

$MTE_{in}2$ = ± 0.606 inWC [$1\sigma$]

Converting to % dP span,

$MTE_{in}2$ = ± (0.606 inWC/200 inWC)*100%

**$MTE_{in}2$ = ± 0.303% dP span**

2.3.3 Calibration Standard Error **STD2**

The calibration standard error is considered to be negligible (Section 5.8).

$$\mathbf{STD_{in}2 = 0}$$

2.3.4 Calibration Error **CAL2**

The total calibration error for the M&TE is:

$$CAL2 = \pm [MTE_{in}2^2 + STD_{in}2^2]^{1/2}$$

$$= \pm [0.303^2 + 0^2]^{1/2}$$

$$\mathbf{CAL2 = \pm 0.303\ \%\ dP\ span}$$

2.3.5 Setting Tolerance **ST2**

The transmitter is calibrated as part of a loop calibration, and the PPC output is verified to ± 3.04 % (3.04 gpm) (Reference 4.6.9). This is considered a 3σ value since all calibrations meet this tolerance.

Converting to 1σ;

$$ST2 = \pm 3.04\ gpm / 3$$

$$= \pm 1.013\ gpm$$

Expressed as a percent of nominal flow at rated conditions:

$$ST2_{nom} = \pm 1.013\ gpm/64\ gpm * 100$$

$$= \pm 1.583\ \%$$

Converting to % of dP span at 64 gpm using equation G10 from Reference 4.1.1:

$$\%\ full\ span\ dP\ error = (2 * \%\ nominal\ flow\ error)/(F_{max}/F_{nom})^2$$

where $F_{max}$ and $F_{nom}$ are expressed in % of $F_{nom}$

$$\%\ F_{max} = (100/64) * 100$$

$$= 156.25\%$$

$$ST2 = (2 * 1.583\ \%)/(156.25/100)^2$$

$$\mathbf{ST2 = 1.297\ \%dP\ span}$$

2.3.6 Drift Error **D2**

Drift error for the transmitter is ± 0.2% of URL / 6 months, taken as a random $2\sigma$ value (paragraph 1.3). The calibration frequency is 2 years, with a late factor of 6 months.

$D2_{2\sigma} = \pm (0.2\% * URL)$

Drift is applied to the surveillance interval as follows (Reference: 4.1.1 Appendix A)

$D2_{2\sigma} = \pm [0.002\ URL]\ [(24\ months + 6\ months) / 6\ months]^{1/2}$

$= \pm (0.002 * 750\ inWC)\ (30/6)^{1/2}$

$= \pm 3.354\ inWC$

Converting to a $1\sigma$ value

$D2_{1\sigma} = \pm 3.354\ inWC\ / 2$

$D2_{1\sigma} = \pm 1.677\ inWC$

Converting to % dP span,

$D2_{1\sigma} = \pm (1.677\ inWC / 200\ inWC) * 100\%$

$\mathbf{D2_{1\sigma} = \pm 0.839\%\ dP\ span}$

2.3.7 Power Supply Effects **$\sigma$2PS**

Power supply effects are considered to be negligible (Section 5.7). Therefore,

$\mathbf{\sigma 2PS = \pm 0}$

2.3.8 Ambient Temperature Error **$\sigma$2T**

The temperature effect is ± (0.5% URL + 0.5% calibrated span)/100°F [$2\sigma$] (paragraph 1.3). The maximum temperature at the transmitter location is 118°F, and normal temperature during calibration is considered to be 73°F, so the maximum difference = 118-73°F = 45°F

$\sigma 2T_{2\sigma} = \pm [(0.005 * 750\ inWC + 0.005 \times 200\ inWC) / 100°F] \times 45°F \quad [2\sigma]$

$\sigma 2T_{2\sigma} = \pm 2.138\ inWC$

Converting to a $1\sigma$ value

$\sigma 2T_{1\sigma} = \pm 2.138\ inWC / 2$

$\sigma 2T_{1\sigma} = \pm 1.069\ inWC$

Converting to % dP span,

$\sigma 2T_{1\sigma}$= ± (1.069 inWC / 200 inWC)*100%

**$\sigma 2T_{1\sigma}$= ± 0.534% dP span**

2.3.9 Random Input Error **σ2in**

Random input error to Module 2 is equal to the random output error from Module 1, therefore

**σ2in = σ1 = ± 0.5% dP span**

2.3.10 Total Random Error **σ2**

$$\sigma 2 = \pm [(RA2)^2 + (CAL2)^2 + (ST2)^2 + (D2)^2 + (\sigma 2PS)^2 + (\sigma 2T)^2 + (\sigma 2in)^2]^{1/2}$$

$$\sigma 2 = \pm [(0.1)^2 + (0.303)^2 + (1.297)^2 + (0.839)^2 + (0)^2 + (0.534)^2 + (0.5)^2]^{1/2}$$

**σ2 = ± 1.739 % dP span**

2.4 Flow Transmitter Errors (Module 2) Non-Random Error, **Σe2**

2.4.1 Humidity Error **e2H**

No humidity effect errors are provided in the manufacturer's specifications, and the humidity conditions at the instrument location are within the operating limits of the module. Therefore, humidity errors are considered negligible during normal conditions. (Reference 4.1.1, Appendix I)

**e2H = 0**

2.4.2 Radiation Error **e2R**

No radiation errors are provided in the manufacturer's specifications. Therefore, it is reasonable to consider the normal radiation effect as negligible and capable of being calibrated out in accordance with Appendix I of Reference 4.1.1. Therefore,

**e2R = 0**

2.4.3 Seismic Error **e2S**

No seismic effect errors are provided in the manufacturer's specifications. A seismic event defines a particular type of accident condition. Therefore, there is no seismic error for normal operating conditions (Section 5.7)

**e2S = 0**

2.4.4 Vibration Effect e2V

The error due to vibration is considered to be negligible because it is small and there is no difference between normal operating and calibration conditions with respect to vibration effects (Section 5.7).

**e2V = 0**

2.4.5 Static Pressure Error **e2SP**

The transmitter has a Zero Error of ±0.25% of URL per 2000 psi and a Span Error of ±0.25% of Input Reading per 1000 psi (paragraph 1.3). Therefore the total Static Pressure Error is

**e2SP** = ±0.25% of URL per 2000psi + 0.25% of Input Reading per 1000psi

The nominal process pressure is 1005psig (paragraph 1.6). Therefore, the Zero error is:

$e2SP_Z$ = ± 0.25% * 750 "WC * 1005 psig / 2000 psi

= ± 0.942 "W.C.

Calculating the input dP at 64 gpm:

Input dP = $(64\text{ gpm}/100\text{ gpm})^2$ * 200 "W.C.

= 81.92 "W.C.

Calculating the Span Error:

$e2SP_{Sp}$ = ± 0.25% * 81.92 "WC * 1005 psig / 1000 psi

$e2SP_{Sp}$ = ± 0.206 "W.C.

Therefore, the combined Zero and Span error, **e2SP,** is:

e2SP = $e2SP_Z + e2SP_{Sp}$

e2SP = ± [0.942 "W.C. + 0.206 "W.C.]

e2SP = ± 1.148 "W.C.

Converting to % dp span,

e2SP = ± (1.148 "W.C./200 "W.C.) *100%

**e2SP = ± 0.574 % dp span**

2.4.6 Ambient Pressure Error **e2P**

The flow transmitter is an electrical device and therefore not affected by ambient pressure.

**e2P = 0**

2.4.7 Temperature Error **e2T**

Temperature error is considered to be a random variable for a Rosemount transmitter. Therefore

**e2T = 0**

Non-Random Input Error **e2in**

**e2in = Σe1 = 0**

Total Non-Random Error **Σe2**

$\Sigma e2 = e2H + e2R + e2SP + e2S + e2V + e2P + e2T + e2in$

$= 0 + 0 \pm \mathbf{0.574} + 0 + 0 + 0 + 0 + 0$

$\mathbf{\Sigma e2 = \pm 0.574}$ **% dp span**

2.5 PPC I/O Module Errors (Module 3) Random Error, **σ3**

2.5.1 Reference Accuracy **RA3**

Reference Accuracy is specified as ± 0.50% of full scale voltage (paragraph 1.4) and considered to be a 2σ value (Section 5.6)

$RA3_{2\sigma} = \pm 0.50\% \text{ x FSV}$

$RA3_{2\sigma} = \pm 0.005 \text{ x } 160 = 0.8\text{mV}$

Converting to inWC and 1σ,

$RA3_{1\sigma} = \pm [0.8\text{mV} * (200 \text{ inWC} / (160\text{mV} - 32\text{mV}))] / 2$

$RA3_{1\sigma} = \pm 0.625 \text{ inWC}$

Converting to % dp span,

$RA3_{1\sigma} = \pm (0.625 \text{ inWC}/200\text{inWC}) * 100\%$

**$RA3_{1\sigma}$ = ± 0.313% dp span**

2.5.2 Calibration Error **CAL3**

The I/O module is not calibrated; the indication is verified during the calibration of Module 1. Therefore,

**CAL3 = ± 0**

2.5.3 Setting Tolerance **ST3**

The I/O module is not calibrated and no operator adjustments are made which could introduce errors due to a calibration process. The computer output is verified to read ± 2.2 gpm as part of the loop calibration. Therefore, the Setting Tolerance is included as part of the transmitter calibration.

**ST3 = ± 0**

2.5.4 Drift Error **D3**

The vendor does not specify a drift error for the I/O module. Per Section 3.13, it is considered to be included in the specification for Reference Accuracy.

**D3 = ± 0**

2.5.5 Input error due to Signal Resistor **σ3r**

A ± 0.1% tolerance resistor is connected across the input to the I/O card to develop the voltage signal read by the card (Section 2.4.1). The ± 0.1% tolerance is considered to be a 2σ value (Section 5.6). The transmitter is scaled to provide a 4-20 mA output for 0-200 "W.C. dP input. At nominal flow (64 gpm), the dP presented to the transmitter is:

Calculating dP at 64 gpm:

$dP_{rated}$ = (64 gpm / 100 gpm)$^2$ * 200 "W.C.

= 81.920 "W.C.

At this dP, the transmitter output is:

Flow Signal Out = (81.920/200) * 16 mA + 4 mA

= 10.554 mA

Therefore, the maximum error due to the resistor at rated flow (64 gpm) with the I/O card scaled for 32 – 160 mV equal to 0 – 200 "W.C. (paragraph 1.2) is

$\sigma 3r_{2\sigma} =$ $\pm (0.001) * 8\ \Omega$

$=$ $\pm 0.008\ \Omega$

Converting to voltage error at the input to the I/O card:

$\sigma 3r_{2\sigma} =$ $\pm (0.008\ \Omega * 10.554$ mA

$=$ $\pm 0.084$ mV

Converting to " W.C.:

$\sigma 3r_{2\sigma} =$ $\pm [(0.084\ \text{mV}/(160 - 32\ \text{mV})) * 200$ "W.C.]

$\sigma 3r_{2\sigma} =$ $\pm 0.132$ "W.C.

Converting to a $1\sigma$ value;

$\sigma 3r_{1\sigma} =$ $\pm 0.132$ "W.C./2

$\sigma 3r_{1\sigma} =$ $\pm 0.066$ "W.C.

Converting to % of dP span;

$\sigma 3r_{1\sigma} =$ $\pm (0.066$ "W.C. / 200 "W.C.)* 100

**$\sigma 3r_{1\sigma} =$ $\pm 0.033$ % of dP span**

2.5.6 Random Input Error **σ3in**

$\sigma 3in$ = $\sigma 2$ = $\pm 1.739$ % dp span

**$\sigma 3in$ = $\pm 1.739$ % dP span**

2.5.7 Total Random Error **σ3**

$\sigma 3 = \pm [(RA3)^2 + (CAL3)^2 + (ST3)^2 + (\sigma 3r)^2 + (\sigma D3)^2 + (\sigma 3in)^2]^{1/2}$

$\sigma 3 = \pm [(0.313)^2 + (0)^2 + (0)^2 + (0.033)^2 + (0)^2 + (1.739)^2]^{1/2}$

**$\sigma 3$ = $\pm 1.767$ % dP span**

2.6 PPC I/O Module Errors (Module 3) Non-Random Error, **Σe3**

2.6.1 Humidity Error **e3H**

No humidity effect errors are provided in the manufacturer's specifications. Also, the I/O module is located in EQ Zone C1A, where humidity under normal conditions may vary from 20 to 50%

RH (Ref. 2.4.8). Therefore, humidity errors are negligible during normal conditions. (Reference 4.1.1, Appendix I)

**e3H** = **0**

2.6.2 Radiation Error **e3R**

No radiation errors are provided in the manufacturer's specifications. Also, the instrument is located in the Control Room, EQ Zone C1A, a mild environment (Section 2.4.8). Therefore, it is reasonable to consider the normal radiation effect as negligible and capable of being calibrated out in accordance with Appendix I of Reference 4.1.1. Therefore,

**e3R** = **0**

2.6.3 Seismic Error **e3S**

No seismic effect errors are provided in the manufacturer's specifications. A seismic event defines a particular type of accident condition. Therefore, there is no seismic error for normal operating conditions (Section 5.7).

**e3S** = **0**

2.6.4 Static Pressure Offset Error **e3SP**

The I/O module is an electrical device and therefore not affected by static pressure.

**e3SP** = **0**

2.6.5 Ambient Pressure Error **e3P**

The I/O module is an electrical device and therefore not affected by ambient pressure.

**e3P** = **0**

2.6.6 Process Error **e3Pr**

The I/O module receives an analog current input from the flow transmitter proportional to the pressure sensed. Any process errors associated with the conversion of pressure to a current signal have been accounted for as errors associated with module 1. Therefore,

**e3Pr** = **0**

2.6.7 Non-Random Input Error **e3in**

**e3in** = **Σe2** = **± 0.574 % dp span**

Total Non-Random Error **Σe3**

$\Sigma e3 \;=\; e3H + e3R + e3S + e3SP + e3P + e3Pr + e3in$

$= 0 + 0 + 0 + 0 + 0 + 0 \pm 0.574$

$\mathbf{\Sigma e3 \;=\; \pm 0.574}$ **% dp span**

2.7 CRD Flow Rate Uncertainty Total Error, TE

$TE \;=\; 2{*}\sigma3 + \Sigma e3$

To convert % dp span to lbm/hr

Converting 0.0320 Mlbm/hr to GPM:

Weight of water at 4 °C (≈40 °F)

1000 kg $m^{-3}$ (specific gravity = 1)

1 kilogram = 2.2046226218 lbs

Therefore 1 $m^3$ of water at 4 °C weighs

1000 kg $m^{-3}$ * 2.2046226218 lbs/kg = 2,204.623 lbs $m^{-3}$

1 gallon = 0.003785 $m^3$ [US, liquid]

1 gallon = 2,204.623 lbs $m^{-3}$ * 0.003785 $m^{-3}$

1 gallon = 8.3445 lbs

Or 1 lb = 0.1198 gal (gallons/lb)

1 hour = 60 min (min/hr)

Lbm * gal/lb/[(hr*min/hr) * sp] = gal/min (at specific gravity sp)

1 Lbm/hr = (1 * 0.1198)/(60 * 1) = 0.0020 GPM

At a temperature of 80 °F, the specific gravity of water is

996.56 kg/$m^3$/1000 kg $m^{-3}$ = 0.997

Therefore,

1 Lbm/hr = (1 * 0.1198)/(60 * 0.997) = 0.0020 GPM

At 80 °F: 0. 0320 Mlbm/hr = 64 gpm

Converting errors to % nominal flow (using Equation G10 in Ref. 4.1.1)

Nominal flow = 64 gpm = 100% flow

Full Span = 100/64*100 = 156.250% flow

% flow error $= (\% \text{ dp span} / 2) * (F_{max}/F_{nom})^2 + (\% \text{ dp span} / 2) * (F_{max}/F_{nom})^2$

$= (1.767 / 2) * (156.250 \% / 100 \%)^2 + (0.574/ 2) * (156.250 \% / 100 \%)^2$

$\sigma 3 + \Sigma e3$ = ± [2.157 % flow + 0.701 % flow] [1σ]

Converting to a 2σ value,

TE = ± [(2*2.157 % flow) + 0.701 % flow]

**TE = ± 5.015 % flow**

3.0 The uncertainty calculated for the CRD flow at rated conditions of 64 gpm is ± 5.015 % of flow. Therefore;

$TE_{flow}$ = ± (5.015 % * 64 gpm)/100

$TE_{flow}$ = ± 3.210 gpm [2σ]

Converting to lbm/hr for water at 80 °F

$TE_{lbm}$ = ± (3.210 gpm) * (8.3445 lbs/gal @ sp. Gr. = 1) * (0.997 sp. Gr. @ 80 °F) * 60 min/hr

$TE_{lbm}$ = ± 1602.329 lbm/hr

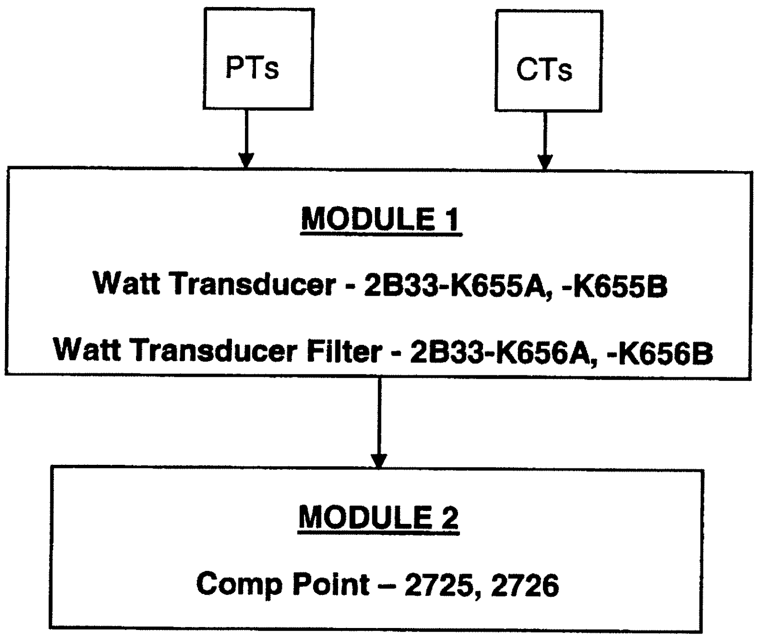
This value is entered into the table in Section 2.4 for CRD flow under Uncertainty.

The purpose of this Appendix is to calculate the uncertainty in the measurement of Reactor Recirculation Pump Motor Power for input to the table in Section 2.4 of this calculation.

1.0 Recirculation Pump Motor Power Measurement Loop Configuration

1.1 Each analyzed instrument loop consists of Current Transformers, Potential Transformers, a Watt Transducer, a Watt Transducer Filter, and a PPC input/output (I/O) module. There is a separate instrument loop for each of the Reactor Recirculation Pump motors. Since the two loops are identical, the instrument uncertainty of one loop will be calculated and then the two uncertainties combined SRSS to provide the uncertainty in the combined power measurement for both pumps

The vendor specifies a combined accuracy for the watt transducer and watt transducer filter which is considered to include the CT and PT inputs. Therefore, they will be addressed as one module. The loop is shown as:




1.2 Watt Transducer EPN 2B33-K655A, -K655B (Refs. 4.4.1, 4.2.4 & 4.6.2):

| | |
|---|---|
| Volts: | 120 |
| Amps: | 0 – 5 A |
| Output Range | 0-1 mA |
| Setting Tolerance | ±5% of full scale |
| Location | 2H13-P612 |

1.3 Watt Transducer Filter EPN 2B33-K656A, -K656B (Refs. 4.4.1, 4.6.2 and 4.6.14):

| | |
|---|---|
| Amps: | 0 – 1 mA |
| Output Range: | 0-100 mV |
| Process Range: | 0-14.4 MW ) |
| Location | 2H13-P612 |

1.4 The Watt Transducer and Filter have a combined accuracy of ± 0.5 % (Ref. 4.4.1)

1.5 Pump Motor Efficiency (Ref. 4.4.1):

| | |
|---|---|
| At 100% Load: | 94.4% |
| At 75% Load: | 93.5% |
| At 50% Load: | 91.5% |
| At 25% Load: | 85.0% |

1.6 PPC I/O (low level analog input) cards for computer point IA2725, IA2726 (Ref. 4.3.9 & 4.5.1):

RTP 8436-32 8 Channel Isolated Low Level Analog Input Card performance specifications (Ref. 4.5.1)

| | |
|---|---|
| Accuracy: | ±0.50% of full scale (32°F to 131°F) |
| Full Scale Voltage: | ±160 mV |

1.7 Local Service Environments (Reference: 4.6.1):

| | 2H13-P612 | Plant Process Computer |
|---|---|---|
| EQ Zone | C1A | C1A |
| Location | Aux. Elec. Equip. Rm. | Control Room (Computer Room) |
| Temperature Range | 50°F to 104°F (Normal: 65 to 85°F) | 50°F to 104°F (Normal: 65 to 85°F) |
| Pressure | 0.125 to 3.0 "wc | 0.125 to 3.0 "wc |
| Humidity | 2.6 to 90% RH (Normal: 20-50%) | 2.6 to 90% RH (Normal: 20-50%) |

2.0 Reactor Recirculation Pump Motor Power Measurement Loop Uncertainty

2.1 Watt Transducer and Filter (Module 1) Random Error, $\boldsymbol{\sigma 1}$

2.1.1 Reference Accuracy **RA1**

Per paragraph 1.4, the combined accuracy of the transducer and filter is ±0.5% of range. Per Section 5.6, this is considered to be a 2σ number.

Therefore,

$RA1_{2\sigma}$ = ± 0.50% * 14.4 MW

$RA1_{2\sigma}$ = ± 0.072 MW

Converting to 1σ value,

$RA1_{1\sigma}$ = ±0.072/2 MW

$\mathbf{RA1_{1\sigma}}$ = **±0.036 MW**

2.1.2 Calibration Error **CAL1**

The test equipment used to calibrate the Watt Transducer and Filter are assumed to be at least as accurate if not better than the equipment being calibrated. Therefore, the M&TE uncertainty will be taken as the Reference Accuracy of the Watt Transducer and Filter. Per Section 5.6, this is considered to be a 2σ number.

M&TE = RA1 = ±0.5% of range

M&TE = ± 0.072 MW

**CAL1 = M&TE = ± 0.072 MW**

Converting to 1σ value,

$CAL1_{1\sigma}$ = ±0.072/2 MW

$\mathbf{CAL1_{1\sigma}}$ = **±0.036 MW**

2.1.3 Setting Tolerance **ST1**

The setting tolerance is ±5% of full scale (Reference: 4.6.2). This is considered to be a 3σ number.

Therefore,

$ST1_{3\sigma} = \pm 5\% * 14.4$

$ST1_{3\sigma} = \pm 0.72$ MW

Converting to 1σ value,

$ST1_{1\sigma} = \pm 0.72/3$ MW

$\mathbf{ST1_{1\sigma} = \pm 0.24}$ **MW**

2.1.4 Drift Error **D1**

The vendor did not publish a separate drift specification. Therefore, per Reference 4.1.1 Appendix A, a drift error of ± 0.5% of span per refueling cycle is assumed for electronic components. This is considered to be a 2σ number. Therefore,

$D1 = \pm 0.5\% * 14.4$ MW

$\mathbf{D1 = \pm 0.072}$ **MW**

Converting to 1σ value,

$D1 = \pm 0.072/2$ MW

$\mathbf{D1 = \pm 0.036}$ **MW**

2.1.5 Power Supply Effects **σ1PS**

Power supply effects are considered to be negligible (Section 5.10). Therefore,

$\boldsymbol{\sigma}\mathbf{1PS = 0}$

2.1.6 Ambient Temperature Error **σ1T**

The vendor did not publish a separate temperature effect specification. The Watt Transducer and Filter are located in the auxiliary electrical room which is a controlled environment. Therefore, per Section 5.any temperature error is considered to be included in the reference accuracy.

**$\sigma 1T$ = 0**

2.1.7 Random Input Error **$\sigma 1in$**

The watt transducer and filter are the first devices in the instrument loop. Therefore,

**$\sigma 1in$ = 0**

2.1.8 Total Random Error **$\sigma 1$**

$$\sigma 1 = \pm [(RA1)^2 + (CAL1)^2 + (ST1)^2 + (D1)^2 + (\sigma 1PS)^2 + (\sigma 1T)^2 + (\sigma 1in)^2]^{1/2}$$

$$\sigma 1 = \pm [(0.036)^2 + (0.036)^2 + (0.24)^2 + (0.036)^2 + (0)^2 + (0)^2 + (0)^2]^{1/2}$$

**$\sigma 1$ = ± 0.2480 MW**

2.2 Watt Transducer and Filter (Module 1) Non-Random Error, **$\Sigma e1$**

The watt transducer and filter are electrical devices and their output is not subject to environmental or vibration effects. Therefore;

**$e1H = e1R = e1P = e1T = 0$**

2.2.1 Seismic Error **e1S**

A seismic event is an abnormal operating condition and is not addressed by this calculation (Section 5.7). Therefore;

**e1S = 0**

2.2.2 Static Pressure Error **e1SP**

The watt transducer and filter are electrical devices not affected by process pressure. Therefore;

**e1SP = 0**

2.2.3 Non-Random Input Error **e1in**

The watt transducer and filter and their associated CTs and PTs are the first devices in the instrument loop. Therefore;

**e1in = 0**

2.2.4 Total Non-Random Error **Σe1**

$\Sigma e1 = e1H + e1R + e1P + e1T + e1S + e1SP + e1in$

$\Sigma e1 = 0 + 0 + 0 + 0 + 0 + 0 + 0$

$\mathbf{\Sigma e1 = \pm 0}$

2.3 PPC I/O Module Errors (Module 2) Random Error, **σ2**

2.3.1 Reference Accuracy **RA2**

Reference Accuracy is specified as ± 0.50% of full scale (paragraph 1.6) and considered to be a 2σ value (Section 5.6)

$RA2_{2\sigma} = \pm 0.50\% * \text{full scale}$

$RA2_{2\sigma} = \pm 0.50\% * 14.4MW = 0.072\ MW$

Converting to 1σ,

$RA2_{1\sigma} = \pm 0.072 / 2$

$\mathbf{RA2_{1\sigma} = \pm 0.036\ MW}$

2.3.2 Calibration Error **CAL2**

The I/O module is not calibrated; the indication is verified during the calibration of Module 1. Therefore,

**CAL2 = ± 0**

2.3.3 Setting Tolerance **ST2**

The I/O module is not calibrated and no operator adjustments are made which could introduce errors due to a calibration process. The output of the PPC I/O module is verified as part of the loop calibration of Module 1. Therefore,

**ST2 = ± 0**

2.3.4 Drift Error **D2**

The vendor does not specify a drift error for the I/O module. Therefore, per Section 3.13, it is considered to be included in the reference accuracy.

**D2 = ± 0**

2.3.5 Random Input Error $\sigma 2in$

$\sigma 2in$ = $\sigma 1$ = ± 0.2480 MW

**$\sigma 2in$ = ± 0.2480 MW**

2.3.6 Total Random Error $\sigma 2$

$$\sigma 2 = \pm [(RA2)^2 + (CAL2)^2 + (ST2)^2 + (\sigma D2)^2 + (\sigma 2in)^2]^{1/2}$$

$$\sigma 2 = \pm [(0.036)^2 + (0)^2 + (0)^2 + (0)^2 + (0.2480)^2]^{1/2}$$

**$\sigma 2$ = ± 0.2506 MW**

2.4 PPC I/O Module Errors (Module 2) Non-Random Error, $\Sigma e2$

2.4.1 Humidity Error **e2H**

The I/O module is located in EQ Zone C1A, where humidity may vary from 20 to 50% RH (Ref. 4.6.1). Humidity errors are negligible during normal conditions. (Reference 4.1.1, Appendix I)

**e2H = 0**

2.4.2 Radiation Error **e2R**

The instrument is located in the Control Room, EQ Zone C1A, a mild environment (Section 2.5.7). Therefore, it is reasonable to consider the normal radiation effect as negligible and capable of being calibrated out in accordance with Appendix I of Reference 4.1.1. Therefore,

**e2R = 0**

2.4.3 Seismic Error **e2S**

No seismic effect errors are provided in the manufacturer's specifications. A seismic event defines a particular type of accident condition. Therefore, there is no seismic error for normal operating conditions (Section 5.7).

**e2S = 0**

2.4.4 Static Pressure Offset Error **e2SP**

The I/O module is an electrical device and therefore not affected by static pressure.

**e2SP = 0**

2.4.5 Ambient Pressure Error **e2P**

The PPC I/O card is an electrical device and therefore not affected by ambient pressure.

**e2P = 0**

2.4.6 Process Error **e2Pr**

The PPC I/O card is an electronic device mounted in the Control Room and is not subjected to any process effects.. Therefore,

**e2Pr = 0**

2.4.7 Non-Random Input Error **e3in**

**e2in = Σe1 = ± 0**

2.4.8 Total Non-Random Error **Σe2**

Σe2 = e2H + e2R + e2S + e2SP + e2P + e2r + e2in

= 0 + 0 + 0 + 0 + 0 + 0 + 0

**Σe2 = 0**

2.5 Recirculation Pump Motor Power Total Error (one pump motor)

$TE_{1\sigma} = \sigma 2 + \Sigma e2$

$= \pm 0.2506$ MW + 0

$TE_{1\sigma} = \pm 0.2506$ MW

Converting to a 2σ value,

$TE_{2\sigma} = 2*\sigma 2 + \Sigma e2$

$= \pm 2*0.2506$ MW + 0

$\mathbf{TE_{W1p} = \pm 0.501}$ **MW**

2.6 Total Recirculation Pump Motor Power Error (two pump motors)

$$TE_{W2p} = \pm((0.501\ MW)^2 + (0.501\ MW)^2)^{½}$$

$$\mathbf{TE_{W2p} = \pm\ 0.709\ MW}$$

The total uncertainty in the measurement of Reactor Recirculation Pump Motor Power is ± 0.709 MW. This number will be entered in the table in Section 2.4 for RR Pump Motor Power under Uncertainty.